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6th International Methane Hydrate Research and Development Workshop

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14. ABSTRACT

This document reviews the 6th International Methane Hydrate Research and Development Workshop. Researchers from the Norway, Japan and United States have held a series of these workshops in Honolulu, Hawaii; Washington, DC; Vina del Mar, Chile; Victoria, British Columbia; and Edinburgh, Scotland over the last eight years. The primary goals of the workshops are to develop collaborations in field and laboratory research in methane hydrate research that provides sharing of analytical technology, approaches to sampling protocol, and cost sharing of ship time. Twenty-two different nations have participated in previous workshops, resulting in a variety of international collaboration, including methane hydrate exploration off the mid-Chilean Margin, the New Zealand Hikurangi Margin, the Cascadia Margin, and the Gulf of Mexico.

The 6th International Methane Hydrate Research and Development Workshop was focused to enhance international collaboration on development of the methane hydrate research program in the Arctic Ocean. This workshop included participation of representative from 12 countries. Key goals of this workshop include: 1) expanding an international, interdisciplinary scientific network, 2) ship and equipment time and experimental design sharing, 3) coastal ocean data integration, 4) sharing laboratory and field technology information, and 5) discussion on preliminary hydrate dissociation strategies. This workshop focused on topics in the Arctic Ocean, including hydrate exploration and climate change. The session topics during this workshop included: 1) characteristics of hydrate in marine sediments and commercial value of hydrate; 2) laboratory and pilot scale experiments; 3) characterization and quantification of arctic hydrates; 4) exploitation strategies and technical challenges; 5) theoretical modeling; and, 6) methane hydrate fluxes from the ocean and potential climate implications. A summary of the individual topics were discussed with a focus on Arctic hydrates addressing consideration of future challenges and corresponding strategies for extended international collaboration. To stimulate increased international collaboration, each session chair directed conversations toward defining approaches to combine individual nation research focus, funding, and expertise in field and laboratory research. This workshop was scheduled for three days, with focus for the first day pertaining to ocean hydrate research; the second day of the workshop was devoted to conversations on Arctic Ocean research; and the final day was a series of discussions for future development.

15. SUBJECT TERMS

Methane hydrate; Hydrate; Energy; Coastal Ocean; Climate Change

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6th International Methane Hydrate Research and Development Workshop

Bergen, Norway

May 13-15, 2008

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SPONSORS

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I. Introduction

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II. Summary

This 3 day workshop was attended by 55 scientists from 12 countries (Appendix 1). The text through this document is an overview of the presentations and discussions during the workshop. Following this summary key note speaker presentations, summaries of research discussions, and posters are presented. The key issues addressed during the workshop included the following:

1. Future Arctic Ocean research plans need to be developed with a long term field and laboratory research and monitoring plan. As a result of the discussions an international workshop to focus on development of an international Arctic Ocean methane hydrate research program will be planned for the fall of 2008. Topics that will be addressed in the workshop will include an overview of the current Arctic Ocean data, new seismic and pressure core sampling protocol, application of general ocean circulation models

Manuscript approved July 22, 2008.

2. Methane hydrate drilling needs a more thorough evaluation of well production rates that are coupled with production models. There is also a need for exploration protocol and models.
3. Higher resolution seismic profiling needs to be developed and applied. The seismic data need to be coupled with CSEM, shallow sediment porewater geochemistry profiles, and heatflow data for a more thorough evaluation of deep sediment hydrate deposits. Coupling these parameters is intended to provide pre-drilling site evaluation.
4. Laboratory and pilot scale experiments need to focus on geologic accumulation of hydrates, production testing, geomechanic sediment properties, biogeochemical influence on hydrate formation and stability, and sediment thermodynamics.
5. Theoretical modeling needs further development in rock physics flow simulations, geomechanical sediment properties, and environmental system cycling.
6. Production testing needs small scale evaluation to address, environmental impact assessment and regulation, efficiency of hydrate dissociation protocols in terms of pressure and temperature, and flow assurance.

III. Welcome to Bergen Norway

A. Opening Remarks: Bjørn Kvamme, University of Bergen

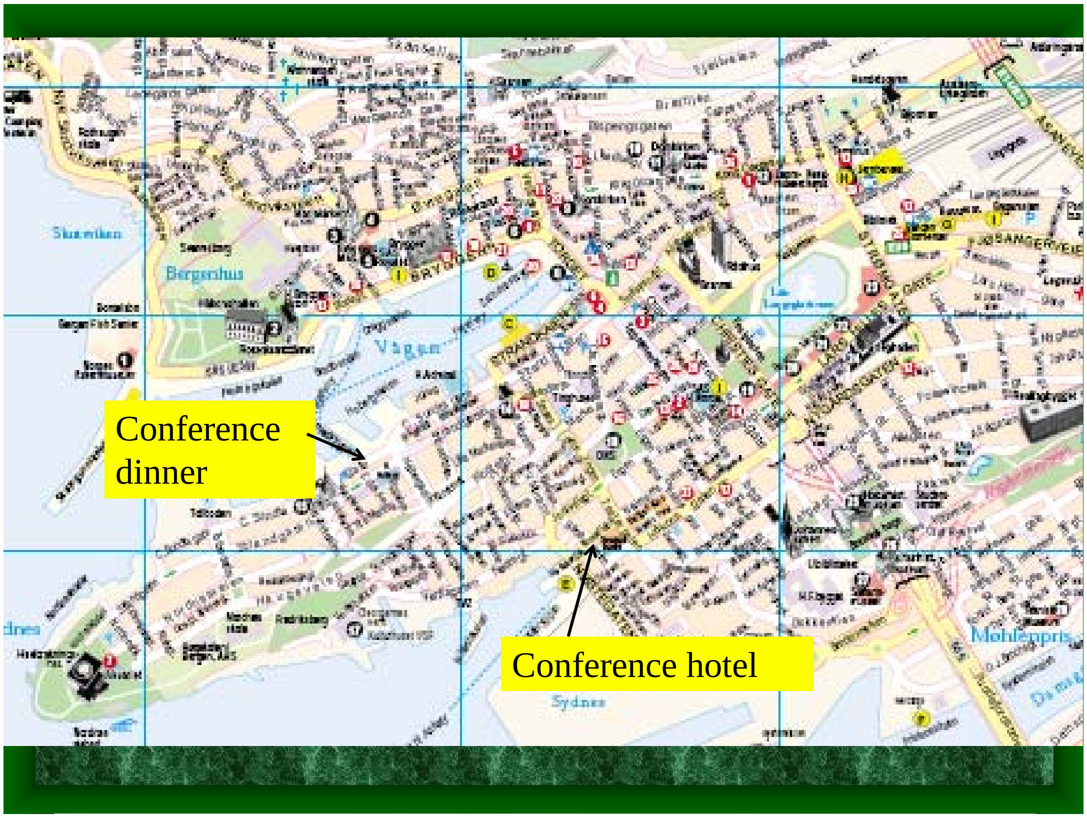
The economic support from our sponsors is highly appreciated and we are also very happy to see that representatives for all sponsors have been able to attend

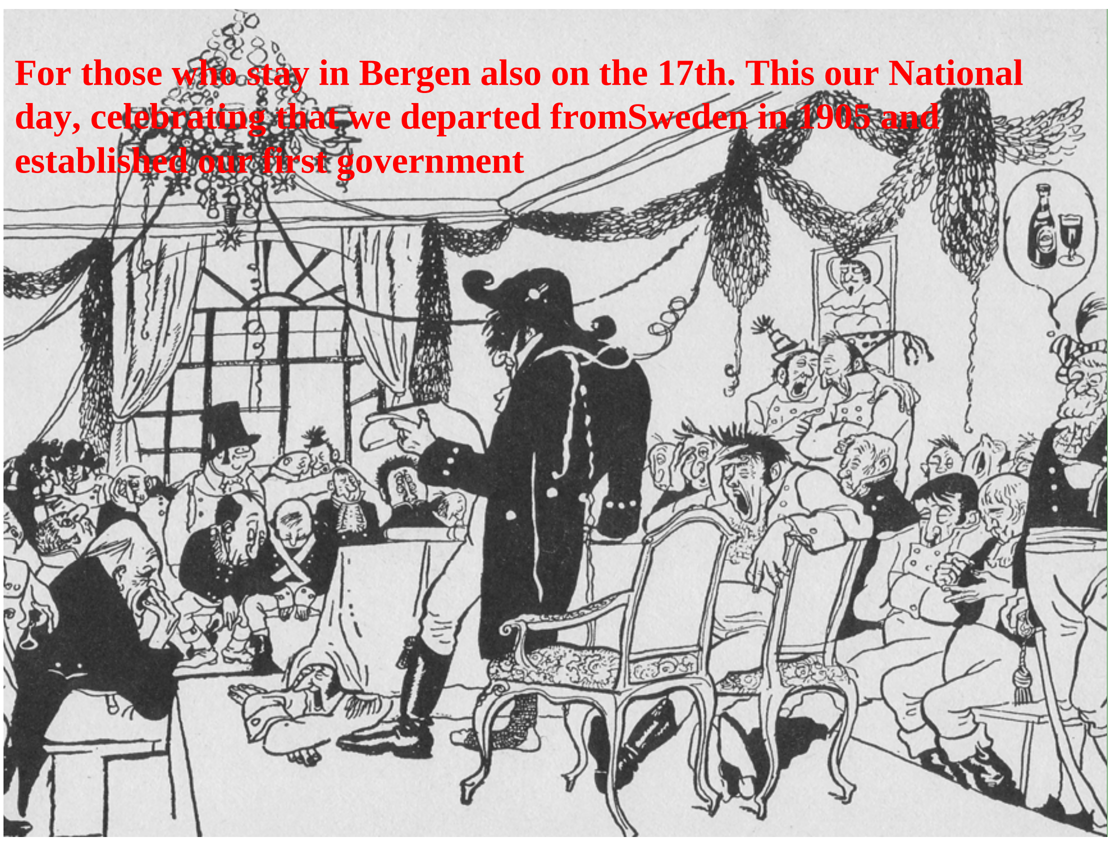
Breakout sessions and rooms will be announced when we know the distribution on the different groups

- Three PhD students will assist in guiding you to the different rooms
- ***Shunping Liu***
- ***Alla Sapranova***
- ***Pilvi-Hilena Kivela***
- These students can also assist in other practical issues like for instance technical assistance in running presentations

Conference dinner

- The conference dinner will be at Hotel Admiral, which is roughly 5 minutes walk from the conference hotel. Taxi will be provided for those who might need that for some reason. Please contact someone in the comittee or our students.
- Dresscode: casual


Conference dinner
Conference hotel
Bergenhus
Vågen
Sydnes


For those who stay in Bergen also on the 17th. This our National day, celebrating that we departed fromSweden in 1905 and established our first government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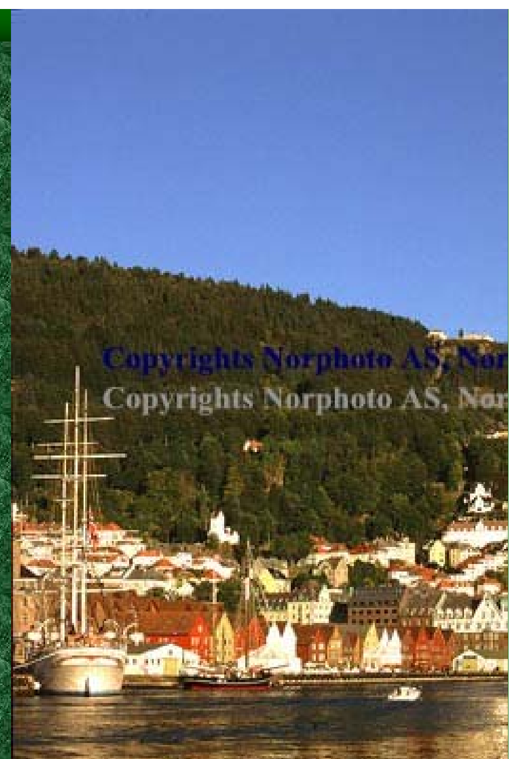
There are parades walking through the city and what is special abour Bergen are corpses with young boys marching with copies of guns

TISSING-LINK

So if drums wake you up early on the 17th you know why



B. Overview of 5th IMHRD – Nick Langhorne, ONRG-London

The **5th International Workshop on Methane Hydrate Research and Development** was held at the **Marriott Dalmahoy Hotel, Edinburgh** from 9-12 October 2006. Approximately 100 scientist from 22 countries attended this workshop. Christian Berndt, Ross Chapman, John Rees, Bahaman Tohidi and Graham Westbrook organized this workshop in Edinburgh. The emphasis was on developing opportunities and overcoming the barriers to international cooperation which may have been perceived in the past. This is to generate more research activity and results through collaboration than could be achieved by individual programmes. Research to date has proved that there are very large amounts of methane trapped in the form of hydrates in deep ocean sediments and permafrost regions. The amount of energy, in the form of hydrates, is estimated to be twice that of all know fossil fuels. These hydrates have had important consequences in the past, as they will in the future. The different aspects of methane hydrate research are covered in this Workshop. These include their role as a source of future energy; their influence on the global carbon balance and associated impact on the past and future climate change; their possible association with sub-sea landslides and tsunamis; their occurrence as potential geohazards, endangering exploration and production activities, as well as those of both civil and military seabed installations. Specific research topics during the workshop included:

- Exploration, mapping and characterization of methane hydrate
  - What controls the distribution of methane hydrates?
  - What are the natural modes of methane hydrate growth in different environments?

- Methane hydrate and geohazards.
  - What is the significance of dissociation, gas overpressure, sediment permeability and hydrate growth to geohazards?
  - Is there evidence that methane hydrates control some geohazards?

- Physical Properties, modelling and lab-scale investigations
  - How can we design experiments to be more relevant?
  - What are the limitations, scaling and variability in the physical properties?

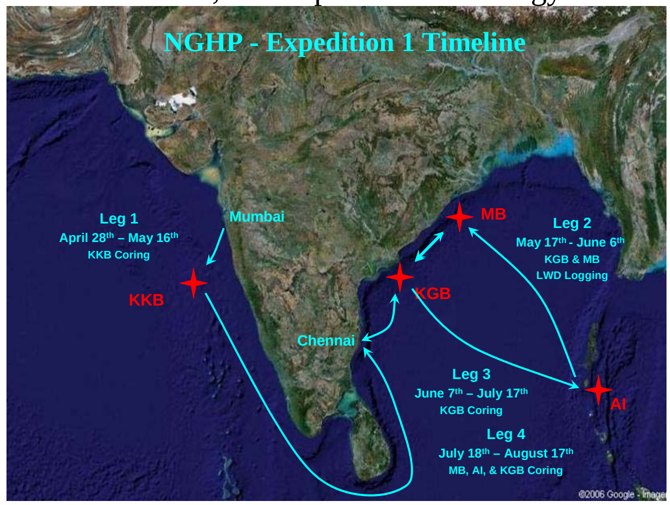
- Methane hydrate as an energy source.
  - What are the climate implications for exploitation as a resource?

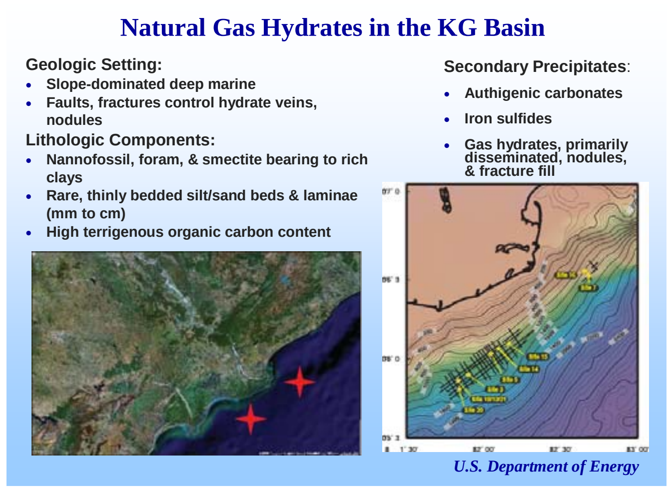
- Seafloor methane flux and climate change.
  - What are the impacts of natural methane flux on climate change?
  - What is the temporal and spatial variability of methane flux to the atmosphere?
  - Can methane hydrate exploitation impact climate?
  - How do the dynamics of methane hydrate influence climate change?

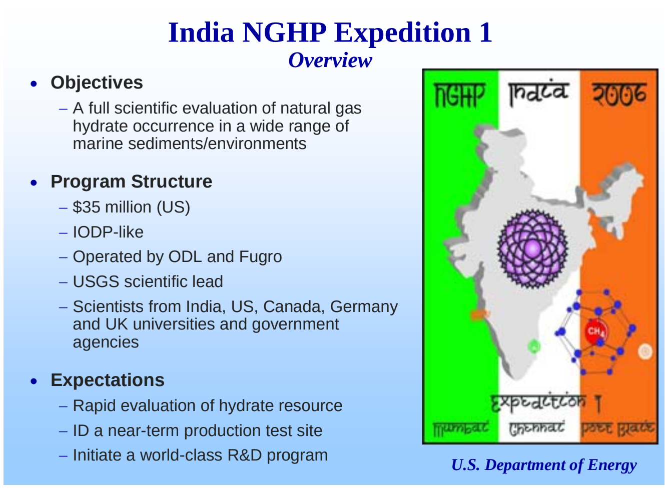
IV. Plenary Session 1: Marine Hydrates

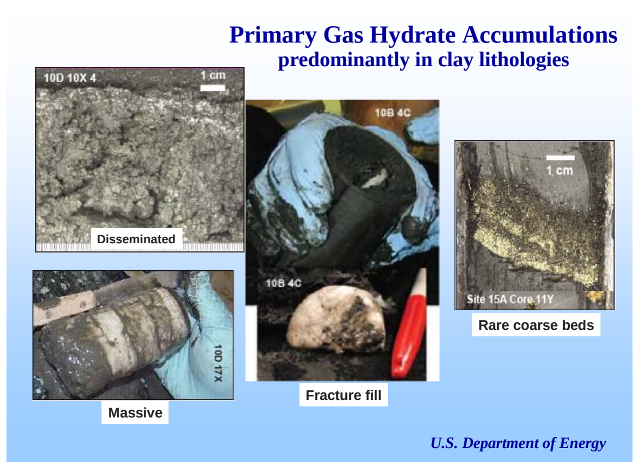
A. Invited Speakers

1. US DOE International Focus: China, Korea and India. Edith Allison, US Department of Energy





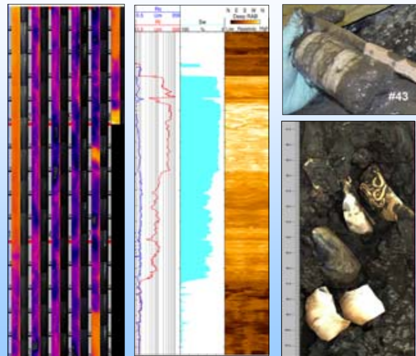




Krishna-Godavari Basin

Site 10/21 - Richest Hydrate Locality Yet Discovered?

- 130-meters of hydrate-bearing section
- Log-calculated GH saturations of 60-80%
- Fracture-controlled distribution w/in a shale matrix
- Limited areal extent



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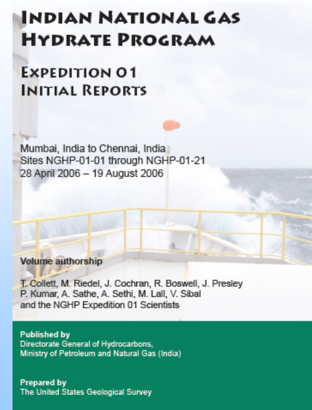

- CD available from US Geological Survey

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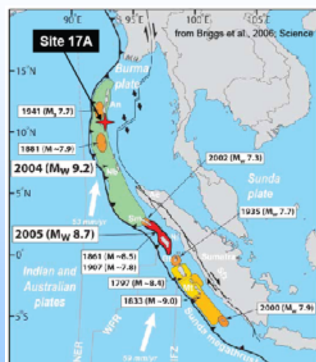
Natural Gas Hydrates in the Andaman Forearc Basin

9cm thick, hydrate bearing, felsic ash bed



- Primary sediment source is marine calcareous & siliceous oozes
- Mafic to felsic ash-falls & volcanoclastic beds (cm thicknesses)
- Ash layers represent volcanic activity from the Miocene to present

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GMGS-1 Gas Hydrate Expedition

April 21st – June 12th, 2007

- Principal Participants
  - Guangzhou Marine Geological Survey (GMGS)
  - China Geological Survey (CGS)
  - The Ministry of Land and Resources of P. R. China
  - Fugro
  - Geotek

Bavenit *(Photo Courtesy of Fugro)*

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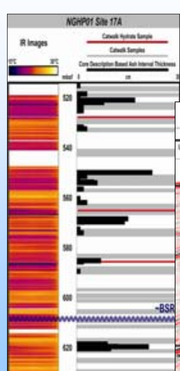
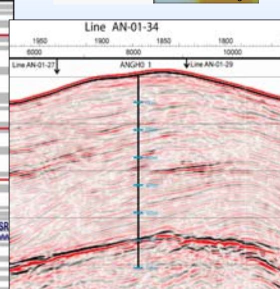
Andaman Islands

World's thickest GHSZ/Deepest Hydrates

- Anomalously deep BSR
- Extremely low temperature gradient
- Hydrate throughout column to 600 mbsf
- Lithologic control on hydrate concentration



Ash bed – Core Photo   Ash bed – IR Image



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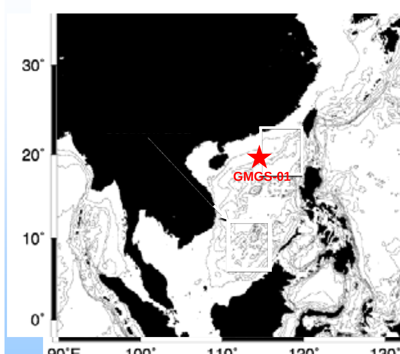
Study Area



- Leg 1: April 21st – May 18th
- Leg 2: May 19th – June 12th
- Explored 8 sites in the South China Sea
- At water depths up to 1500m up to 300mbsf
- Tested precruise 3D seismic and shallow geochemistry based hydrate prospects
- Collect suite of data & samples for post-cruise analyses and synthesis for future expeditions
- Improve understanding of the nature and controls on hydrate occurrences in the South China Sea

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GMGS-01 Shipboard Program

- **Wireline Logging**
  - Complete suite of high precision slimline tools
  - Natural Gamma, Gamma density, Neutron Porosity, Electrical resitivity, caliper, temperature
  - In pipe logging
  - Open hole logging below about 50 mbml
- ***In situ* measurements were also made of temperature & porewater were made using**
  - The Fugro Temperature Probe and
  - The Fugro Porewater Sampler (FPWS)

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GMGS-01 Return to Shore

- **Core data are being correlated with the downhole log data to improve future predictive models of GH concentration**
- **The core and log data will be used to re-examine the seismic data & develop predictive capability from remote datasets**
- **Potential future expeditions to both the Shenhu area and other regions of the northern South China Sea margin are currently under discussion.**

Members of the GMGS-01 science party

Members of the GMGS-01 & Fugro/Geotek science parties

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GMGS-01 Shipboard Program

- **At 8 sites a pilot hole was drilled and wireline logged**
  - Natural Gamma, Gamma Density, Neutron Porosity, Resistivity, Caliper, Temperature
  - Temperature probe and pore-water sampler
- **At 5 of these sites a core hole was drilled 10-15m from original site**
- **Coring**
  - Long wire line piston corer FHPC ~7.5 m
  - Short hammer corer, FC ~3m
  - Short Pressure Corers - FPC and FRPC/HRC
- **Core Analyses**
  - IR Imaging
  - Core Processing
  - MSCL Core logging
  - Pore water Geochemistry
  - Gas analysis
  - Pressure Core Analysis, (X-ray imaging, etc)
  - Cores preserved in liquid nitrogen for later study

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UBGH-1 Gas Hydrate Expedition

September - November, 2007

- **Principal Participants**
  - **KGHDO, KIGAM, KNOC, KOGAS**
  - **Fugro**
  - **Geotek**
  - **McGill University**
  - **NETL/DOE**

Rem Etive

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GMGS-01 Shipboard Program

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Study Area – Ulleung Basin

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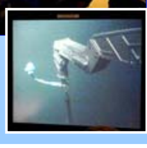
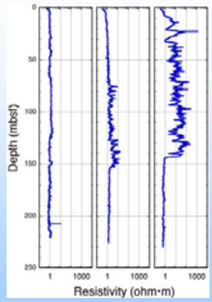
UBGH-01 Leg 1

- Sites selected on pre-expedition analyses of 3D seismic data
- 5 LWD data sets
- 14 ROV surface cores

LWD electrical resistivity from the three "type" locations drilled, showing resistivity profiles differing by orders of magnitude. Gas hydrate was present at all three locations

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Leg 2: Summary

- Documented significant gas-hydrate bearing reservoirs up to 150 mbsf at water depths between 1800 to 2100m
- > 600m of wireline logs
- 38 Conventional cores
- 15 Pressure cores
- 7 Pressure cores stored under pressure
- 10 temperature measurements
- >50 gas samples
- ~ 250 porewater samples
- ~200 sedimentology samples
- Plenty of methane hydrate (~20 samples in liquid nitrogen storage)


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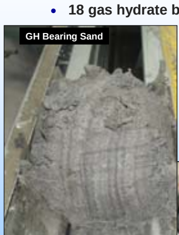
UBGH-01 Hydrates Samples

- Plenty of methane hydrate in various lithologies and forms
- 18 gas hydrate bearing samples preserved



GH Nodules

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Back to Shore…

- The postcruise analysis of the pressure cores was recently completed
  - Will be the subject of a future article in *Fire in the Ice*
  - One core remains stored under pressure for future analysis.

- Post expedition studies include
  - Detailed sedimentological description of split-core sections and analyses of sediment sub-samples
  - Testing of frozen gas-hydrate-bearing sediments
  - Analysis of gas and porewater samples collected shipboard

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US National R&D Program

Contributing to & Benefitting from International R&D

- Multi-national cruises provide scientific access to varied methane hydrate deposits not available to a single country
- Sampling techniques improved during multiple cruises
- Access to natural methane hydrate samples is important for laboratory studies
- International cooperation expands the community of methane hydrate experts

2005, USGS Scientists meeting with scientists from China's

April 2008, Knowledge Economy Minister Lee Yoon-ho with U.S. Secretary of Energy Samuel Bodman

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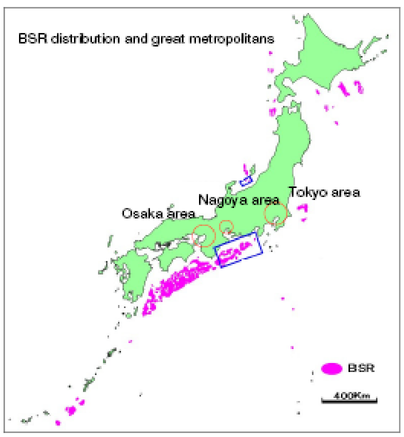
2. Overview of the Japanese National Project on Methane Hydrates. Koji Yamamoto, Japan Oil, Gas, and Metals National Corporation

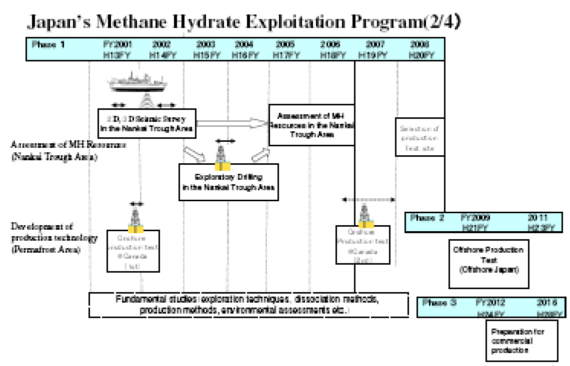
Methane Hydrate, Japanese National Programs

Koji Yamamoto, JOGMEC

Gas hydrate - Japanese National Programs

- METI funded program
  - MH21 and collaborators
    - JOGMEC, AIST, ENAA, private oil&gas companies, universities, engineering companies, etc.
  - Hydrate transport
    - JOGMEC, shipbuilding and plant companies
- MEXT (Ministry of Education, Culture, Sports, Science and Technology) funded programs
  - JAMSTEC – Climate change
  - Universities
- MLITT (Ministry of Land, Infrastructure, Transport and Tourism funding program
  - National Maritime Research Institute
    - CCS related CO_2 hydrate studies
- Private initiatives
  - Hydrate transport, independent studies on production etc.

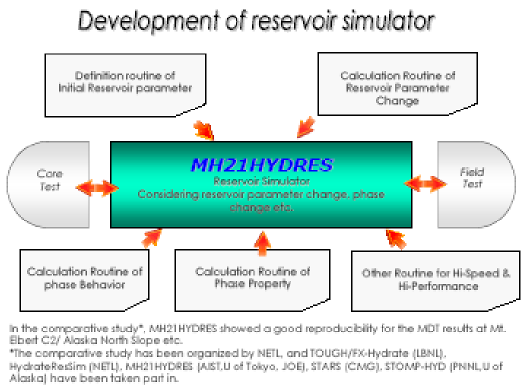


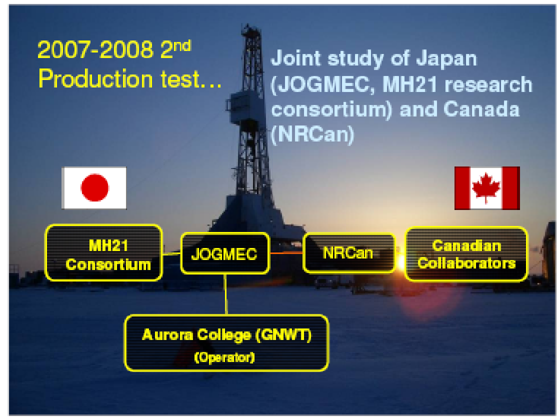


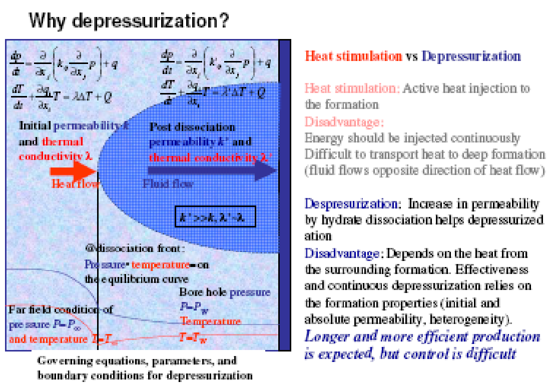
The R&D Subjects of The Group for "Production Methods and Modeling"

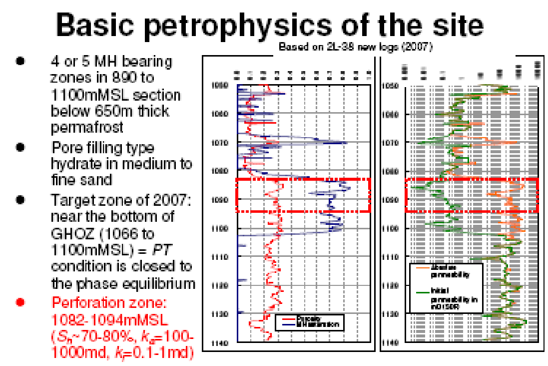
1. *Characterization of MH reservoir properties and evaluation of reservoir parameter*
2. *Modeling of dissociation behavior of MH sediment*
3. *Development of reservoir simulator for MH fields.*
4. *Analysis of dissociation methods*
5. *Preliminary assessment and development of production method.*
6. *To propose methods & conditions for the field production tests.*

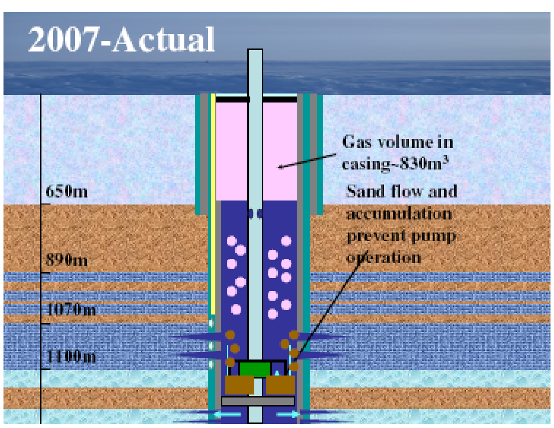
Target reservoir is MH containing sandy sediment

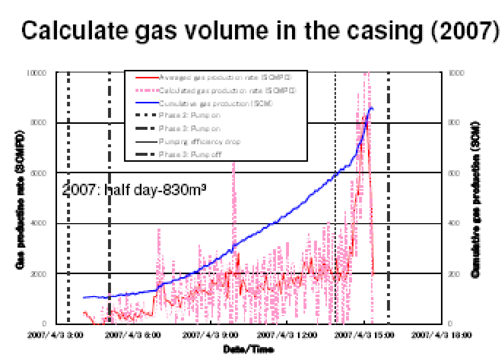

Development of reservoir simulator
Definition routine of Initial Reservoir parameter
Calculation Routine of Reservoir Parameter Change
MH21HYDRES
Reservoir Simulator
Considering reservoir parameter change, phase change etc.
Core Test
Field Test
Calculation Routine of phase Behavior
Calculation Routine of Phase Property
Other Routine for Hi-Speed & Hi-Performance
In the comparative study*, MH21HYDRES showed a good reproducibility for the MDT results at Mt. Elbert C2/ Alaska North Slope etc.
*The comparative study has been organized by NETL, and TOUGH/FX-Hydrate (LBNL), HydrateResSim (NETL), MH21HYDRES (AIST,U of Tokyo, JOE), STARS (CMG), STOMP-HYD (PNNL,U of Alaska) have been taken part in.

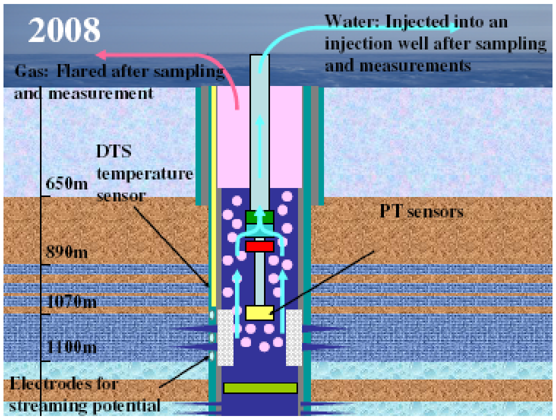

2007-2008 2nd Production test…
Joint study of Japan (JOGMEC, MH21 research consortium) and Canada (NRCan)
MH21 Consortium
JOGMEC
NRCan
Canadian Collaborators
Aurora College (GNWT) (Operator)

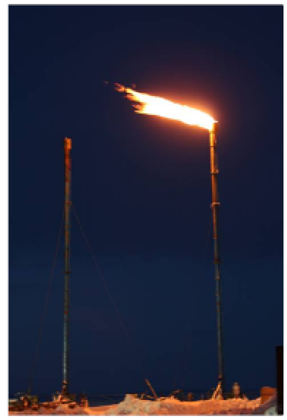

Why depressurization?
Initial permeability k and thermal conductivity λ
Post dissociation permeability k' and thermal conductivity λ'
Heat flow
Fluid flow
k' >> k, λ' ~ λ
@dissociation front: Pressure-temperature on the equilibrium curve
Bore hole pressure $P = P_w$
Temperature $T = T_w$
Far field condition of pressure $P = P_\infty$ and temperature $T = T_\infty$
Governing equations, parameters, and boundary conditions for depressurization
Heat stimulation vs Depressurization
Heat stimulation: Active heat injection to the formation
Disadvantage:
Energy should be injected continuously
Difficult to transport heat to deep formation
(fluid flows opposite direction of heat flow)
Despresurization: Increase in permeability by hydrate dissociation helps depressurized ation
Disadvantage: Depends on the heat from the surrounding formation. Effectiveness and continuous depressurization relies on the formation properties (initial and absolute permeability, heterogeneity).
Longer and more efficient production is expected, but control is difficult


Basic petrophysics of the site
Based on 2L-38 new logs (2007)
4 or 5 MH bearing zones in 890 to 1100mMSL section below 650m thick permafrost
Pore filling type hydrate in medium to fine sand
Target zone of 2007: near the bottom of GHOZ (1066 to 1100mMSL) = PT condition is closed to the phase equilibrium
Perforation zone: 1082-1094mMSL (S_h~70-80%, k_a=100-1000md, k_i=0.1-1md)


2007-Actual
Gas volume in casing~830m³
Sand flow and accumulation prevent pump operation
650m
890m
1070m
1100m


Calculate gas volume in the casing (2007)
2007: half day-830m³
Date/Time

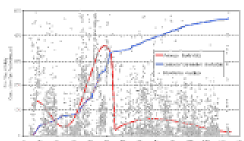




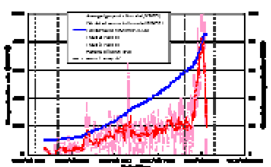
March 10-18, 2008

6 straight days pump operation and sustainable gas production

2002-2007-2008



2002: 5days-470m³



2007 : half day-830m³

2008: 6 days Sustainable Production

Breakthrough!

- *Depressurization really work! -> Efficient and continuous gas production is possible!!*
  - *Gas dissociation was sustained*
  - *Depressurization system worked well*
  - *Gas production volume is in the range of our prediction … Theory and numerical model are OK*
- *More verification for*
  - *Longer time*
  - *Different conditions (eg. Marine sediment)*

Acknowledgements

- *METI (Ministry of Economy, Trade and Industry)*
- *MH21 and collaborators (JOGMEC, AIST, ENAA, etc)*
- *NRCan and collaborators*
- *Aurora College and NWT Government*
- *Imperial Oil Limited*
- *Local communities*
- *Inuvialuit Oil Field Services (IOFS) and IPM Schlumberger*
- *ChevronTexaco, MGM energy corp.*
- *AKITA Drilling, Nabors, other contractors*
- *Partners of 2002 program*
  - *DOE, USGS; USA, GFZ; Germany, MOPNG, GAIL; India, BP-Chevron Texaco Mackenzie Delta Joint Venture*

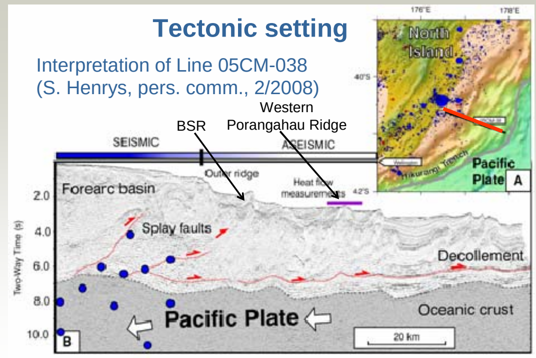
Future of the Japanese National Programs

- **METI Phase 1 program will be finished at the end of FY2008 (March 2009)**
- **What is next?**
  - **Phase 2: Marine production test**
  - **Phase 3: Feasibility study for commercialization**

3. Research Plans and Accomplishments for Hikurangi Margin, Ingo Pecher, Herriot-Watt University

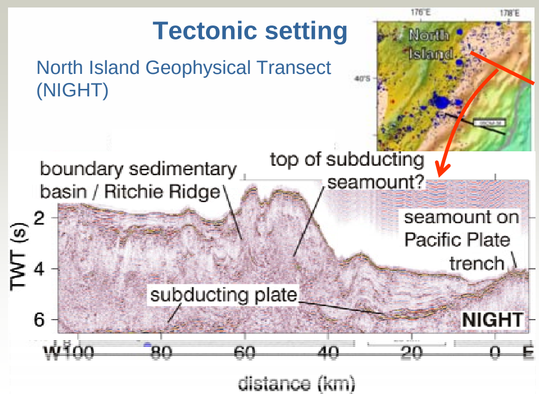
Accomplishments and Research Plans for Gas Hydrates on the Hikurangi Margin, New Zealand

Ingo Pecher, Heriot-Watt University, Edinburgh, UK
Stuart Henrys, GNS Science, Lower Hutt, NZ
Rick Coffin, NRL, Washington, DC, USA
Jens Greinert, University of Ghent, Belgium
Joerg Bialas, IfM-Geomar, Kiel, Germany
TAN0607 & SO191 Scientific Party, and many others

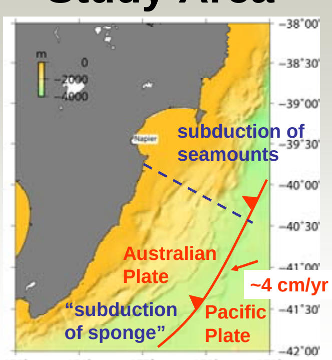


Outline

- Tectonic setting
- History of gas hydrates research on the Hikurangi margin
- Highlights of recent (2005+) surveys
- Research plans
- Discussion – why the Hikurangi margin?



Study Area



Tectonics: Pacific Plate subducted beneath Australian Plate, starting 21 Ma

South: highly accretive ("subduction of sponge")
North: more complex, less accretive to erosive, re-entrants, seamounts subducted

"Subduction of a sponge"

- Rapid accretion (12±3 mm/yr., Barnes and Mercier de Lepinay, 1997)
- Accretionary wedge 100-150 km, significant de-watering >20 m^3/yr per meter along strike
- Very low taper angle
- Fine-grained mudrocks provide cap for significant overpressure (Sibson and Rowland, 2003)

→ "Subduction of a sponge" (Townend, 1997)

Outline

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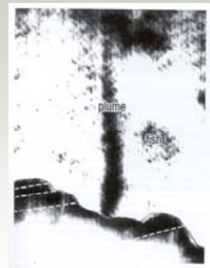
History



- Various fishing vessels and NIWA cruises: Discovery of numerous vent sites and seafloor communities (Lewis and Marshall, 1996)

Vent site L&M 3, Rock Garden, water depth 900 m, plume 300 m high (from Lewis and Marshall, 1996)

History

- First BSRs: Katz (1981, 1982)
- Various crustal surveys
- GeodyNZ survey L'Atalante, 1993:
  Bathymetry + high-speed streamer
  First BSR maps Hikurangi margin
  & Fiordland
  Townend (1997), Henrys et al. (2003)
- Basis for gas hydrates project at GNS funded by NZ Foundation for Science, Research, and Technology (FRST)

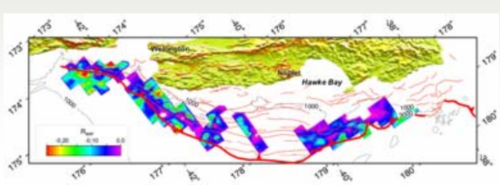
History

- North Island GeopHysical Transect (NIGHT), 2001 – detection of flattennig of Rock Garden + BSRs
- RVIB *N.B. Palmer*, 2003, seismic sea trials, Rock Garden

→ Hypothesis that seafloor erosion linked to gas hydrate freeze-thaw cycles at top of gas hydrate stability (Pecher et al., 2005)

History

- BSR distribution and reflection coefficient (Henrys et al., submitted) largely from GeodyNZ data



History

- R/V *Tangaroa*, 2004, 1 day of bathymetry, water chemistry, towed (METS) sensor

→ Discovery of methane anomaly in water column on southern edge of Rock Garden (Faure et al., 2006)

→ "Faure seeps", more later (SO191)

History

- M/V *Pacific Titan*, 05CM-038, 2005, industry-style seismic line acquired by GNS to analyze potential “sweet spot”, Porangahau Ridge
- R/V *Tangaroa* TAN0607, 2006, first dedicated gas hydrates cruise

Highlights, 2005+

- Rock Garden – seafloor erosion and methane venting
- Porangahau Ridge – focussed fluid expulsion
- Omakere Ridge – higher-order HC (but only there…)
- Wairarapa – CSEM (→ high gas hydrate saturation)

History

- R/V *Tangaroa* TAN0616, 2006, vent sites, first gas hydrates sample
- SO191 (“NewVents”): 2.5 mos. dedicated to gas hydrates and vent sites on the Hikurangi margin
- Here: Focus on last three years: 05CM-038, TAN0607, TAN0616, SO191

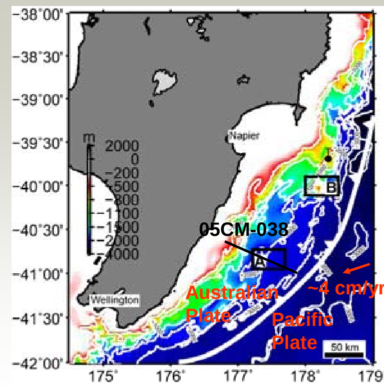


Figure 1: Location map, T: Temperature sensor

TAN0607

B: Rock Garden

A: Porangahau Ridge

Outline

- Tectonic setting
- History of gas hydrates research on the Hikurangi margin
- ▸ Highlights of recent (2005+) surveys
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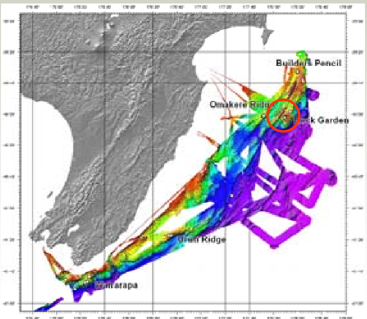
R/V *Tangaroa* TAN 0607

- 20/6-2/7/2006, R/V *Tangaroa*
- Seismic: 45/105 cu-in GI gun, (theoretically) 600-m long streamer (GNS Science, NIWA)
- Heatflow (Davies-Villinger, NRL)
- Coring, pore-water profiles (NRL)
- Coring, paleoceanography (NIWA)
- Water column chemistry (GNS)
- Recover temperature sensor (NIWA)

SO191 Overview: 11. January to 23. March 2007

Five main working areas have been defined for detailed studies during SO191.



Leg 1

MC seismic, side scan, OBS/H, CSEM, MB, equilibrator, ~~deep tow streamer~~

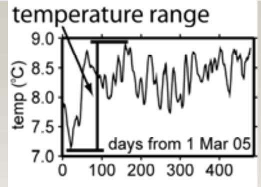
Leg 2

Side scan, lander deployments (FLUFO, BIGO, GasQuant), sediment sampling (GC, MUC), carbonate sampling (TVG), water column sampling, mooring, MB, equilibrator

Leg 3

Lander deployments (FLUFO, BIGO, GasQuant), sediment sampling (GC, MUC), carbonate sampling (TVG), water column sampling, MB, equilibrator and ROV dives

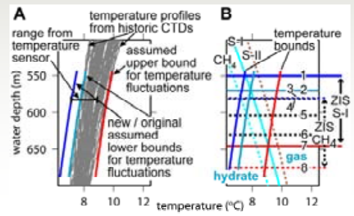
(from J. Greinert, EGU 2008 talk)



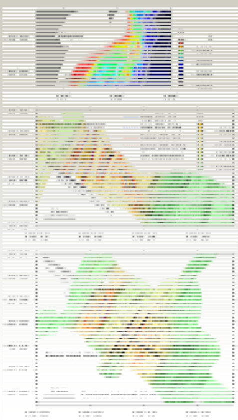
Temperature record

Rock Garden and Ritchie Banks

Fluctuating TGHS
Temperature record
→ Larger range, lower frequency than assumed in Pecher et al. (2005)



Revised level of ZIS
1/7 and 4/8: ZIS
2: Old top of ZIS
3, 5: Ridge crests
6: BSR pinchout in line 2

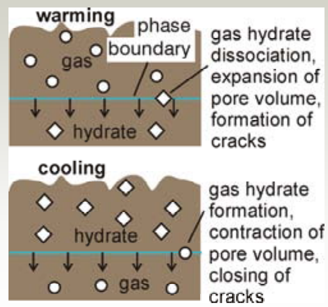


Rock Garden and Ritchie Banks

Seafloor erosion at top of gas hydrate stability?

Bathymetry
ZIS: zone of intermediate stability
S-I: Structure-I forming gas mix
CH4: Methane hydrate in seawater
(see below)

Hypothesis – weakening of sediments from repeated gas hydrate dissociation and formation (Pecher et al., 2005)

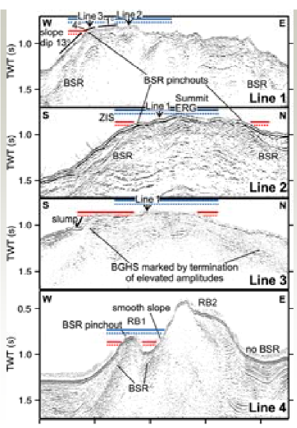


Weakened sediments sliding down ridge, carried away by currents

Only hypothesis (discussion: erosion, penetration of temperature signal, escape of gas, etc.)

Focus on gas release

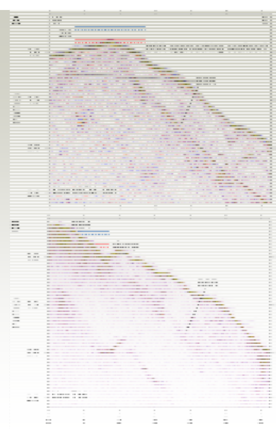
New insights since 2005



Rock Garden and Ritchie Banks

Key observation: edge of flattened plateaus coincides with BSR pinchouts (top of gas hydrate stability, TGHS)

Seismic lines (NPB0304D) across Rock Garden and Ritchie Banks. Red/blue: ZIS as in previous figure; after Pecher et al. (2005) and Pecher et al. (submitted)



Rock Garden and Ritchie Banks

- **Another flattened ridge?**
- **Line T16 beyond ZIS but most of this ridge within it**
- **Slumping, initiated at THGS? (Modelling: Fohrmann et al., 2006)**

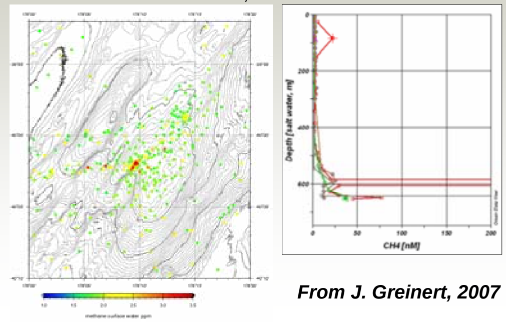
Rock Garden and Ritchie Banks

- **Dredge samples TAN0607 Mudstone seems to be "country rock"**
- **Role of carbonates?**

Mudstones (left), sandstones, carbonates, TAN0607

Rock Garden – Gas Above Faure Seeps

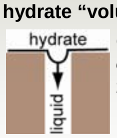
At one CTD station, high CH_4 concentrations were found in only 100 m water depth. Higher concentrations were also detected at the sea surface, but vanished after a storm.



From J. Greinert, 2007

Rock Garden and Ritchie Banks

- **Original hypothesis: Freeze thaw cycles of hydrates lead cracking due to volume expansion from gas release during dissociation**
- **Now: Role of capillary forces in confined spaces: Cracking (or widening of existing cracks) due to hydrate "volume expansion" during formation?**



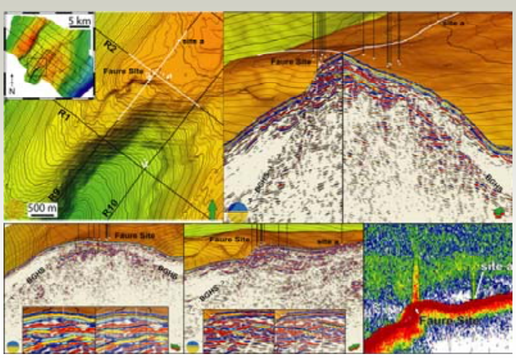
Conceptual model of hydrate growth into cylindrical pore throats leading to capillary forces (after Anderson et al., 2003)

- **Repeated freezing/thawing of water ice common technique to disintegrate mudstones…**
- **Keep in mind: repeated slumping at BGHS, gas column beneath hydrates – only hypothesis!**

Summary – Rock Garden and Ritchie Banks

- **Hypothesis of seafloor erosion: Role of capillary forces during gas hydrate freeze-thaw cycles in mudstones?**
- **Gas conduits that feed vent sites resolved in seismic**
- **Faure seeps, vent site at TGHS, perhaps (!) contributing to elevated methane concentration at sea surface**

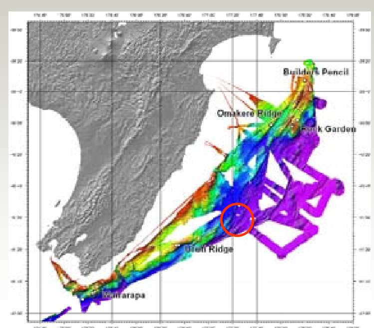
Rock Garden – Gas Beneath Faure Seeps



(after Crutchley et al., in prep.)

Porangahau Ridge

Five main working areas have been defined for detailed studies during SO191.



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Side scan, lander deployments (FLUFO, BIGO, GasQuant), sediment sampling (GC, MUC), carbonate sampling (TVG), water column sampling, mooring, MB, equilibrator

Leg 3

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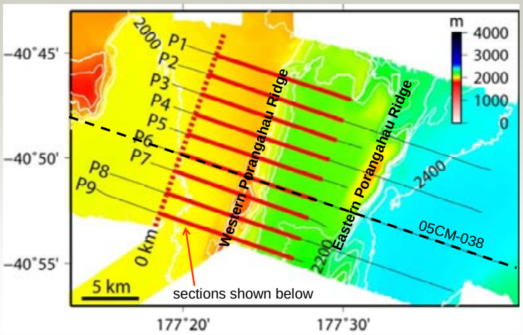
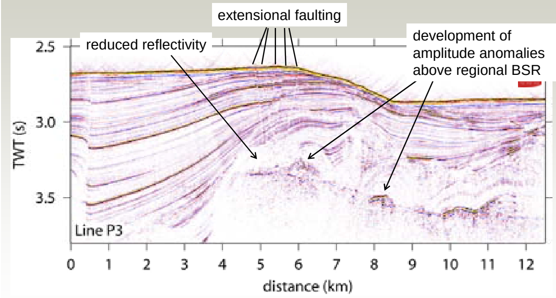
(from J. Greinert, EGU 2008 talk)

TAN0607 tracks

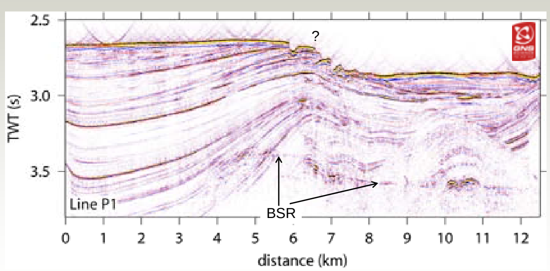


TAN0607, R/V *Tangaroa*: 625 m streamer (initially), 45/105 cu-in GI gun
Processing: NMO (water velocity), stack, migration

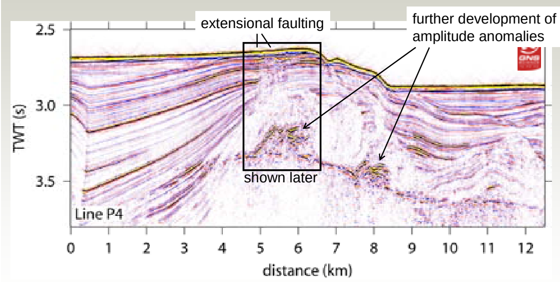
TAN0607 lines



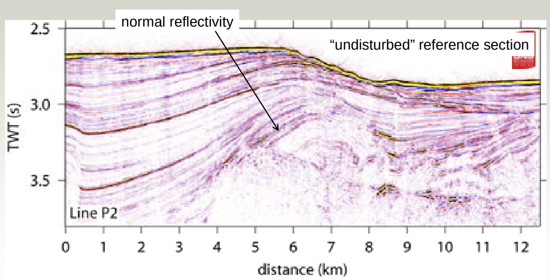
TAN0607 lines



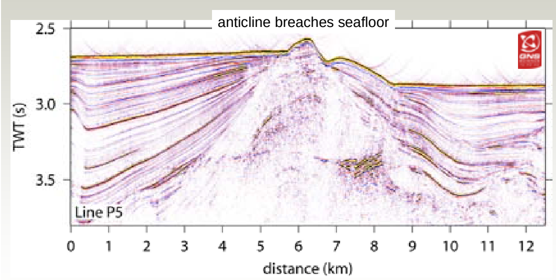
TAN0607 lines



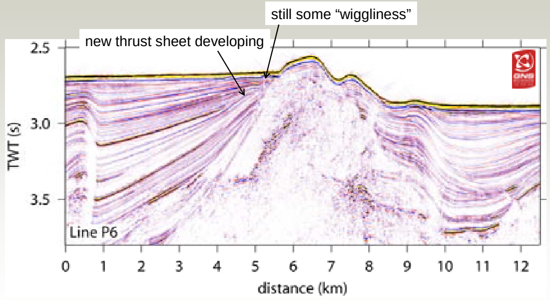
TAN0607 lines



TAN0607 lines

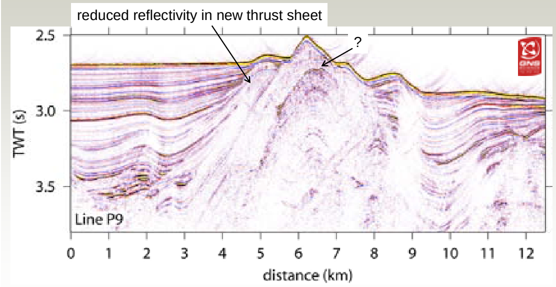


TAN0607 lines

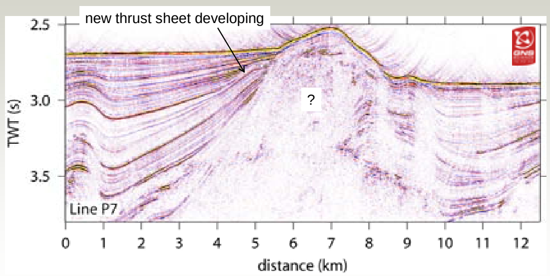


Along 05CM-038 (results from waveform inversion shown later)

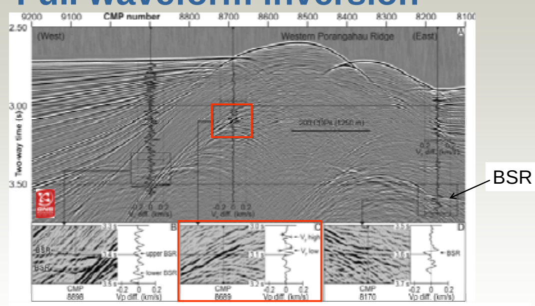
TAN0607 lines



TAN0607 lines

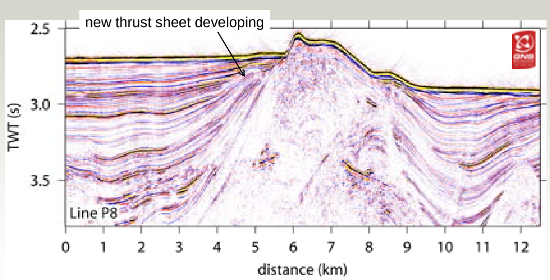


Full waveform inversion

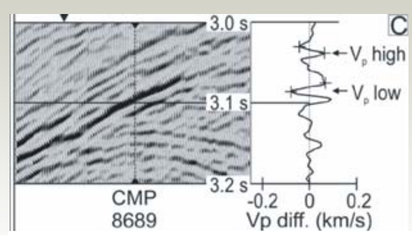


Full waveform inversion on seismic amplitude anomaly above BSR shows high velocities from gas hydrate layer (from Crutchley et al., in prep.)

TAN0607 lines

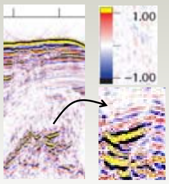


Full waveform inversion



→ Distinct high-velocity layer above low-velocity layer
→ Gas hydrate above gas
→ At phase boundary (local BGHS)
(from Crutchley et al., submitted)

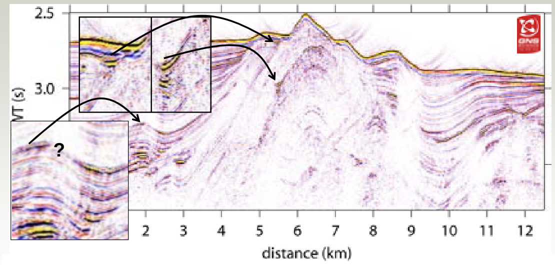
Line P04



- Weaker reflection with positive polarity above strong reflection with negative polarity?

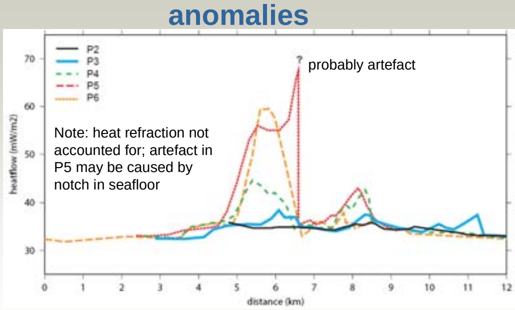
→ Gas hydrates above gas? (Next step: acoustic impedance inversion → S. Toulmin)

Example: Gas and hydrates (?) in steeply dipping faults



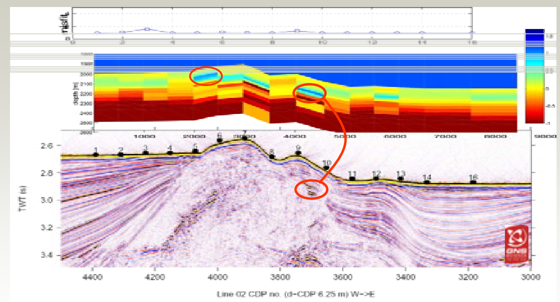
Gas in faults beneath ridge, similar features in slope basins
May explain why we haven't seen any flares or pronounced geochemical anomalies – very localized (and ephemeral?)

Heatflow from top of amplitude anomalies



→ **Strong advective heatflow anomaly, focusing of fluid expulsion**

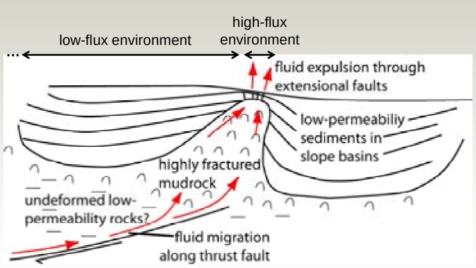
CSEM and Seismic



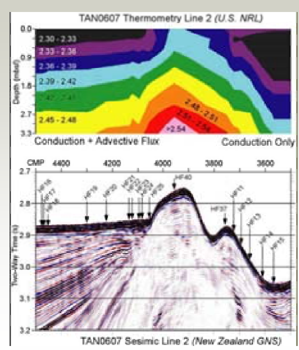
CSEM: K. Schwalenberg, BGR; Seismic: GNS Science

Joint evaluation planned for 7-9/2008, S. Toulmin, K. Schwalenberg

Fluid expulsion on the southern Hikurangi margin



Porangahau Ridge



Porewater Chemistry, Surface Heat Flow, and CSEM
→ Poster Coffin et al.

(Note: heatflow story more complex than pretended for this talk)

Thermal anomaly Warren Wood, pers. comm., 2006
Heatflow data: NRL

Summary – Porangahau Ridge

- **Evidence for strong advective heatflow anomaly**
- → **Focussed fluid expulsion on southern Hikurangi margin along thrust ridges and possibly "pipes" through slope basins**
- **Slope basins otherwise seem to be low-flux environment**
- **Missing link – water chemistry/pore-water chemistry/geophysics**

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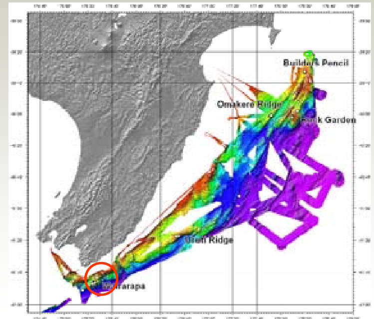


Leg 1

MC seismic, side scan, OBS/H, CSEM, MB, equilibrator, ~~deep tow streamer~~

Leg 2

Side scan, lander deployments (FLUFO, BIGO, GasQuant), sediment sampling (GC, MUC), carbonate sampling (TVG), water column sampling, mooring, MB, equilibrator

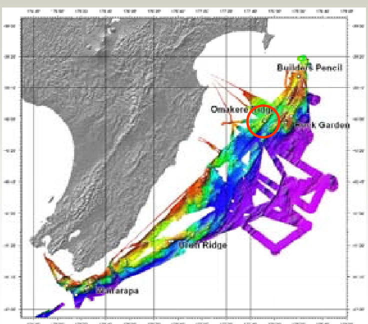
Leg 3

Lander deployments (FLUFO, BIGO, GasQuant), sediment sampling (GC, MUC), carbonate sampling (TVG), water column sampling, MB, equilibrator and ROV dives

(from J. Greinert, EGU 2008 talk)

SO191 Overview: 11. January to 23. March 2007

Five main working areas have been defined for detailed studies during SO191.



Leg 1

MC seismic, side scan, OBS/H, CSEM, MB, equilibrator, ~~deep tow streamer~~

Leg 2

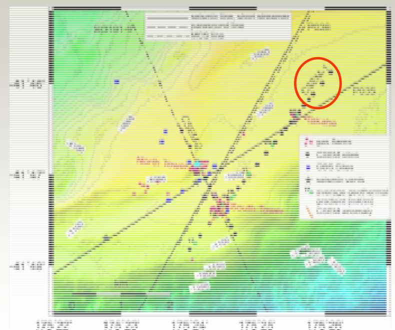
Side scan, lander deployments (FLUFO, BIGO, GasQuant), sediment sampling (GC, MUC), carbonate sampling (TVG), water column sampling, mooring, MB, equilibrator

Leg 3

Lander deployments (FLUFO, BIGO, GasQuant), sediment sampling (GC, MUC), carbonate sampling (TVG), water column sampling, MB, equilibrator and ROV dives

(from J. Greinert, EGU 2008 talk)

Wairarapa – CSEM



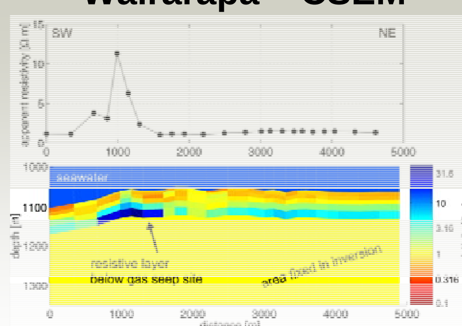
(from Schwalenberg et al., submitted)

Omakere Ridge: Sediment gas composition

One core (MUC-5) at Bear's Paw showed high concentrations of higher HC. Otherwise & elsewhere by far mostly methane *(from J. Greinert, 2007)*

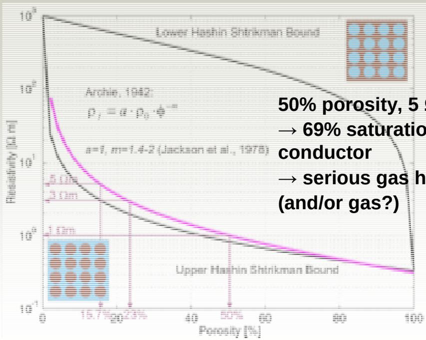
Depth (cm)	Methane (nM)	Ethane (nM)	Propane (nM)	n-Butane (nM)	n-Pentane (nM)	n-Hexane (nM)
0-1	9699	65	58	148	302	315
1-2	8743	9198	9817	8902	7696	6967
2-3	2959	11	6	10	22	14
5-6	16299	226	64	69	200	147
15-16	133746	246	78	139	318	191
		C2/C1	C3/C1	C4/C1	C5/C1	C6/C1
0-1		0.007	0.006	0.015	0.031	0.032
1-2		1.052	1.123	1.018	0.880	0.797
2-3		0.004	0.002	0.003	0.007	0.005
5-6		0.182	0.23	0.31	0.407	0.142
15-16		0.002	0.001	0.001	0.002	0.001

Wairarapa – CSEM



(from Schwalenberg et al., submitted)

Wairarapa – CSEM



50% porosity, 5 Ωm resistivity → 69% saturation with non-conductor → serious gas hydrate conc. (and/or gas?)

(from Schwalenberg et al., submitted)

Outline

- Tectonic setting
- History of gas hydrates research on the Hikurangi margin
- Highlights of recent (2005+) surveys
- ▸ Research plans
- Discussion – why the Hikurangi margin?

Research Plans – NZ

- GNS Science: FRST re-bidding – strong focus of leveraging future international research campaigns
- Canterbury Association of Engineers (K. Chong) – development of gas hydrates strategy aimed at production in the future – seeking additional funding from Ministry of Economic Development

Research Plans – NZ

- Ministry of Economic Development (Crown Minerals) considering to exclude gas hydrates from petroleum permitting (??) – (re-establishment of International Research Corridor for Gas Hydrates)
- Gas Hydrates Roadmap (Beggs et al., 2008) – Economic analysis of the viability of gas hydrates extraction → aiming for extraction by ~2020

Research Plans – NZ+Intl.

- NZ as of 2008 part of IODP consortium (5%?) – future proposals from NZ may have strong gas hydrates component

Research Plans – Intl.

- IfM-Geomar proposal to return with R/V *Sonne,* with GNS leverage (J. Bialas, G. Netzeband, et al.)
  - 3-D SwathSeis + 4-C OBS
  - CSEM
  - Heatflow
  - Gravity coring
  - ROV

  Strong focus on linking gas conduits (3-D seismic) with vents

  Etc., etc. (sorry I am a geophysicist)

Outline

- Tectonic setting
- History of gas hydrates research on the Hikurangi margin
- Highlights of recent (2005+) surveys
- Research plans
- ▸ Discussion – why the Hikurangi margin?

Acknowledgments

- Funding: NZ FRST, Royal Soc. NZ “Marsden”, GNS & NIWA internal funds, ONR-G, NRL, NSF, German BMBF, EU Marie Curie, etc…
- Crews and captains in particular R/V *Tangaroa*, R/V *Sonne*

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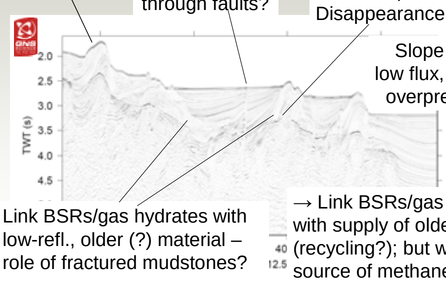
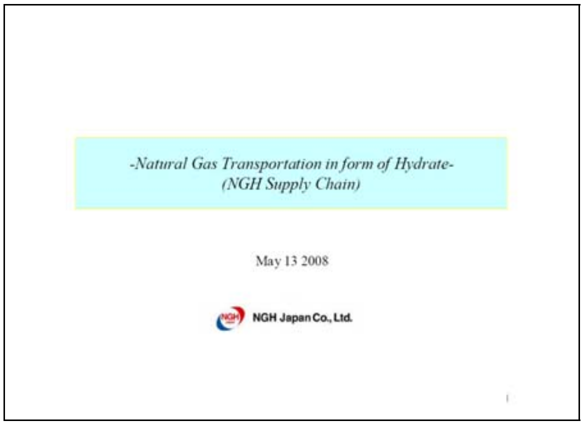
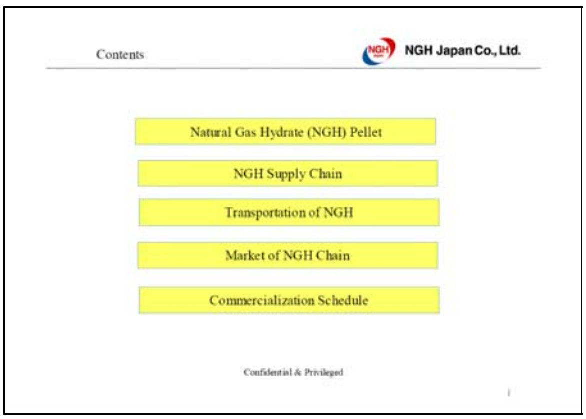
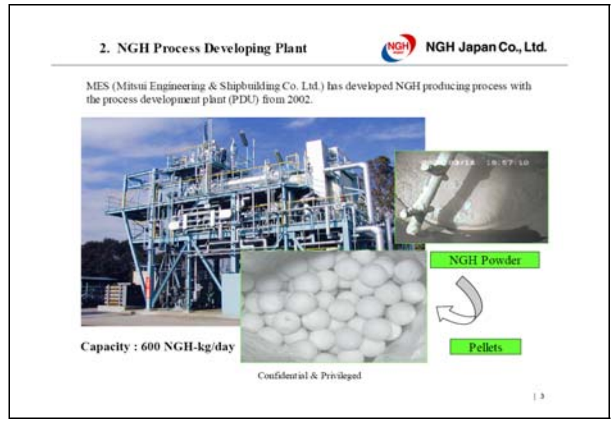
Southern Hikurangi Margin Gas Hydrate System

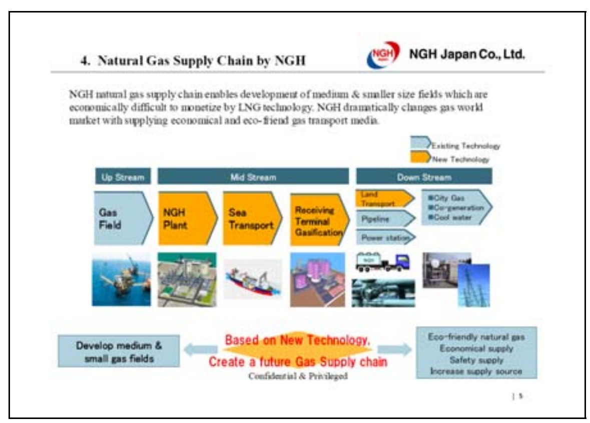


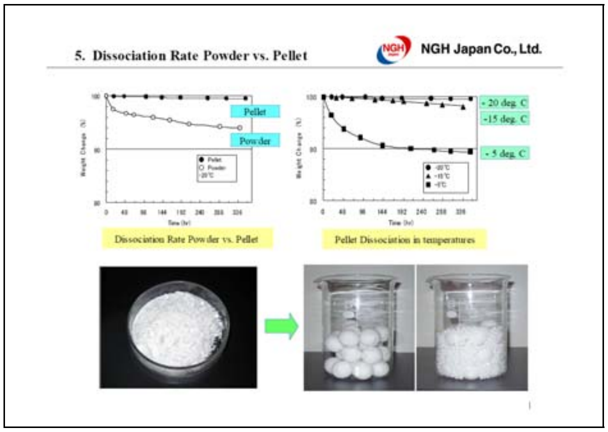
4. Development of Natural Gas Hydrate Transport System. Tatsuya Takaoki, Mitsui Engineering and Shipbuilding Co., LTD.

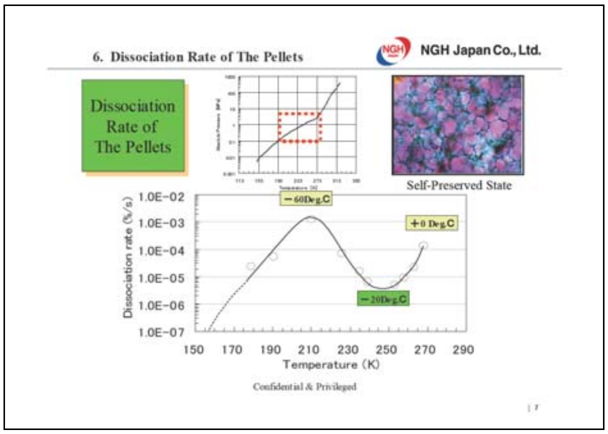









5. Dissociation Rate Powder vs. Pellet
NGH Japan Co., Ltd.
Pellet
Powder
Dissociation Rate Powder vs. Pellet
- 20 deg. C
-15 deg. C
- 5 deg. C
Pellet Dissociation in temperatures


6. Dissociation Rate of The Pellets
NGH Japan Co., Ltd.
Dissociation Rate of The Pellets
Self-Preserved State
−60Deg.C
+0 Deg.C
−20Deg.C
Dissociation rate (%/s)
Temperature (K)
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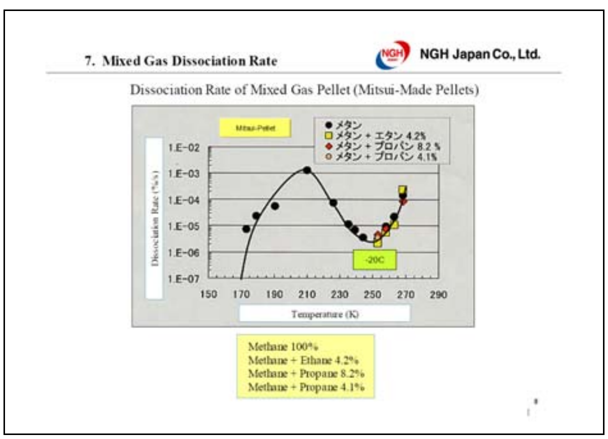
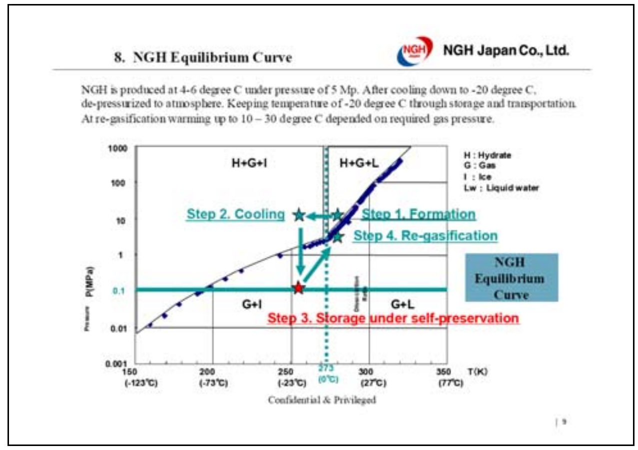
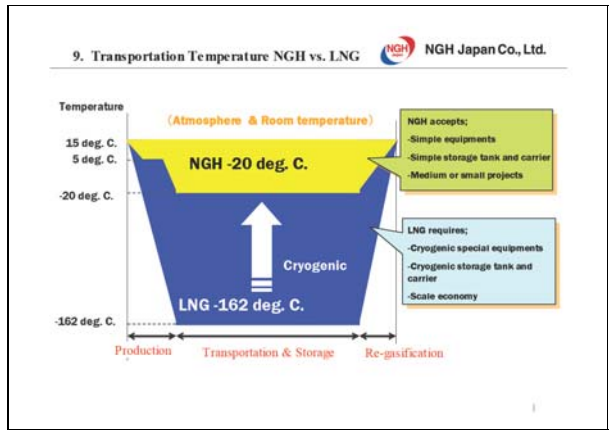
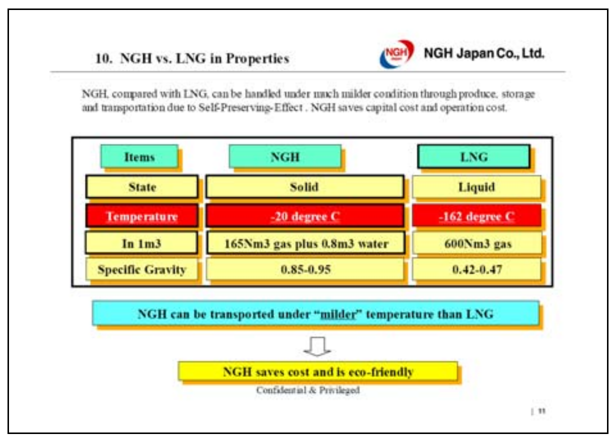
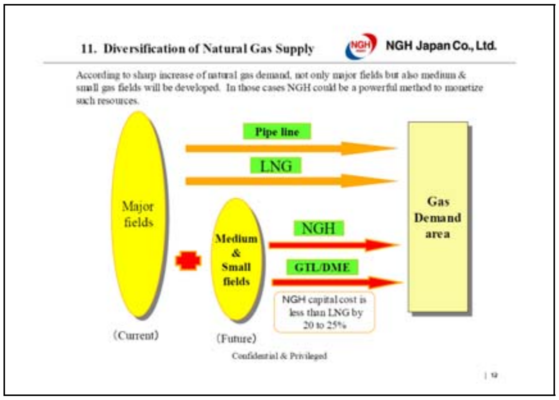
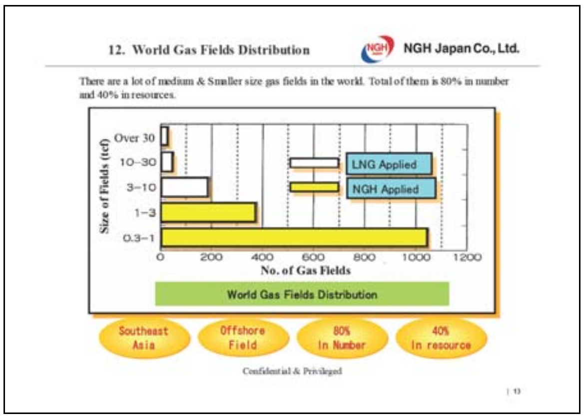

7. Mixed Gas Dissociation Rate
NGH Japan Co., Ltd.
Dissociation Rate of Mixed Gas Pellet (Mitsui-Made Pellets)
Mitsui-Pellet
メタン
メタン + エタン 4.2%
メタン + プロパン 8.2%
メタン + プロパン 4.1%
-20C
Temperature (K)
Methane 100%
Methane + Ethane 4.2%
Methane + Propane 8.2%
Methane + Propane 4.1%


8. NGH Equilibrium Curve
NGH Japan Co., Ltd.
NGH is produced at 4-6 degree C under pressure of 5 Mp. After cooling down to -20 degree C, de-pressurized to atmosphere. Keeping temperature of -20 degree C through storage and transportation. At re-gasification warming up to 10 – 30 degree C depended on required gas pressure.
H+G+I
H+G+L
H : Hydrate
G : Gas
I : Ice
Lw : Liquid water
Step 2. Cooling
Step 1. Formation
Step 4. Re-gasification
NGH Equilibrium Curve
G+I
G+L
Step 3. Storage under self-preservation
T(K)
Confidential & Privileged


9. Transportation Temperature NGH vs. LNG
NGH Japan Co., Ltd.
Temperature
(Atmosphere & Room temperature)
15 deg. C.
5 deg. C.
-20 deg. C.
-162 deg. C.
NGH -20 deg. C.
Cryogenic
LNG -162 deg. C.
NGH accepts;
-Simple equipments
-Simple storage tank and carrier
-Medium or small projects
LNG requires;
-Cryogenic special equipments
-Cryogenic storage tank and carrier
-Scale economy
Production
Transportation & Storage
Re-gasification


10. NGH vs. LNG in Properties
NGH Japan Co., Ltd.
NGH, compared with LNG, can be handled under much milder condition through produce, storage and transportation due to Self-Preserving-Effect. NGH saves capital cost and operation cost.
Items | NGH | LNG
State | Solid | Liquid
Temperature | -20 degree C | -162 degree C
In 1m3 | 165Nm3 gas plus 0.8m3 water | 600Nm3 gas
Specific Gravity | 0.85-0.95 | 0.42-0.47
NGH can be transported under "milder" temperature than LNG
NGH saves cost and is eco-friendly
Confidential & Privileged


11. Diversification of Natural Gas Supply
NGH Japan Co., Ltd.
According to sharp increase of natural gas demand, not only major fields but also medium & small gas fields will be developed. In those cases NGH could be a powerful method to monetize such resources.
Pipe line
LNG
Major fields
Medium & Small fields
NGH
GTL/DME
Gas Demand area
NGH capital cost is less than LNG by 20 to 25%
(Current)
(Future)
Confidential & Privileged


12. World Gas Fields Distribution
NGH Japan Co., Ltd.
There are a lot of medium & Smaller size gas fields in the world. Total of them is 80% in number and 40% in resources.
Size of Fields (tcf)
Over 30
10–30
3–10
1–3
0.3–1
0
200
400
600
800
1000
1200
No. of Gas Fields
LNG Applied
NGH Applied
World Gas Fields Distribution
Southeast Asia
Offshore Field
80% In Number
40% In resource
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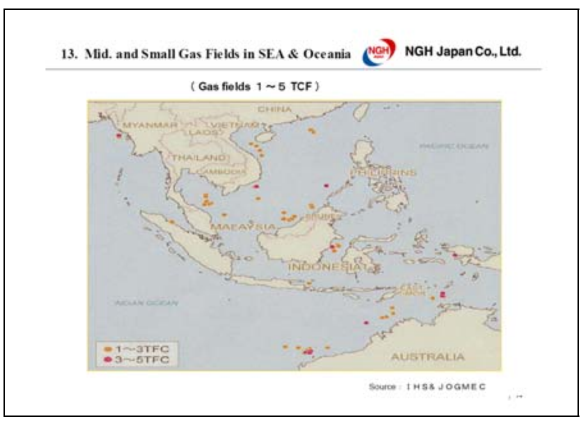
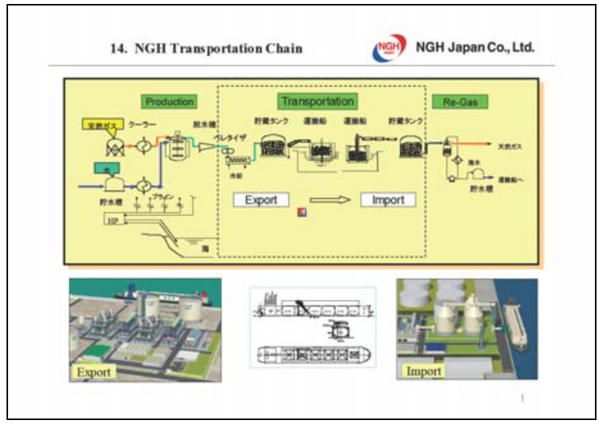
| 13


13. Mid. and Small Gas Fields in SEA & Oceania
NGH Japan Co., Ltd.
(Gas fields 1 ~ 5 TCF)
CHINA
MYANMAR
VIETNAM
LAOS
THAILAND
PHILIPPINES
MALAYSIA
INDONESIA
AUSTRALIA
1~3TFC
3~5TFC
Source : IHS& JOGMEC


14. NGH Transportation Chain
NGH Japan Co., Ltd.
Production
Transportation
Re-Gas
Export
Import
Export
Import


15. NGH Production Plant and Export Terminal
NGH Japan Co., Ltd.
NGH producing plant with capacity of 24,000 tons/day (LNG 1 million tons/year) and export terminal.
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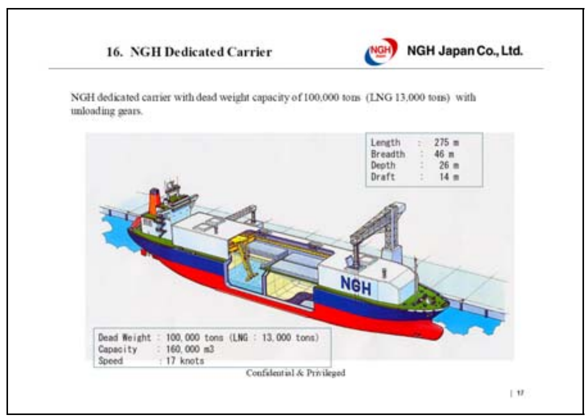
16. NGH Dedicated Carrier
NGH Japan Co., Ltd.
NGH dedicated carrier with dead weight capacity of 100,000 tons (LNG 13,000 tons) with unloading gears.
Length : 275 m
Breadth : 46 m
Depth : 26 m
Draft : 14 m
NGH
Dead Weight : 100,000 tons (LNG : 13,000 tons)
Capacity : 160,000 m3
Speed : 17 knots
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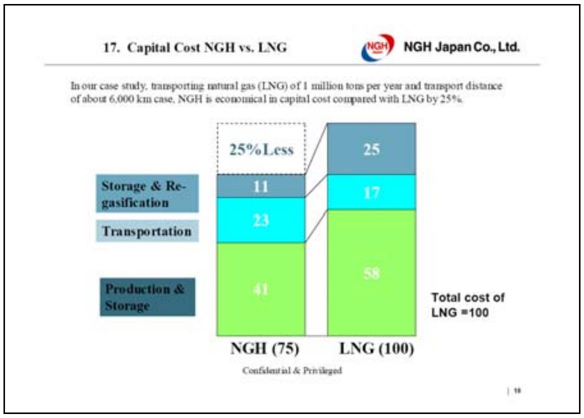
| 17


17. Capital Cost NGH vs. LNG
NGH Japan Co., Ltd.
In our case study, transporting natural gas (LNG) of 1 million tons per year and transport distance of about 6,000 km case, NGH is economical in capital cost compared with LNG by 25%.
25%Less
25
11
17
23
41
58
Storage & Re-gasification
Transportation
Production & Storage
Total cost of LNG =100
NGH (75)
LNG (100)
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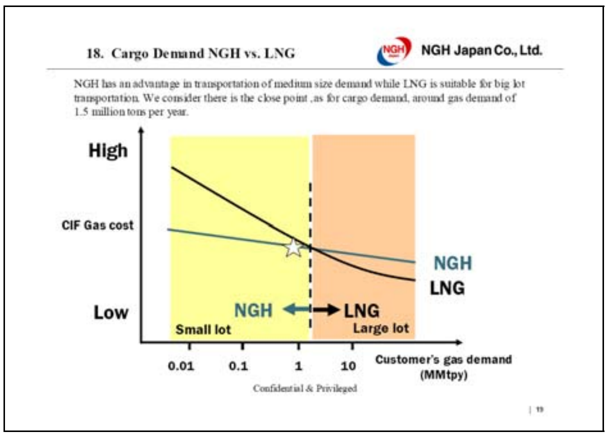
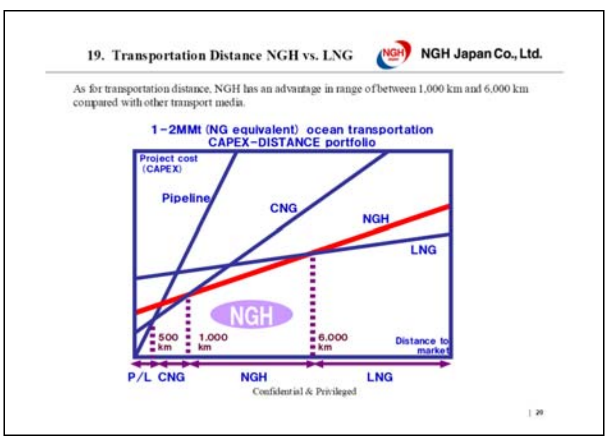
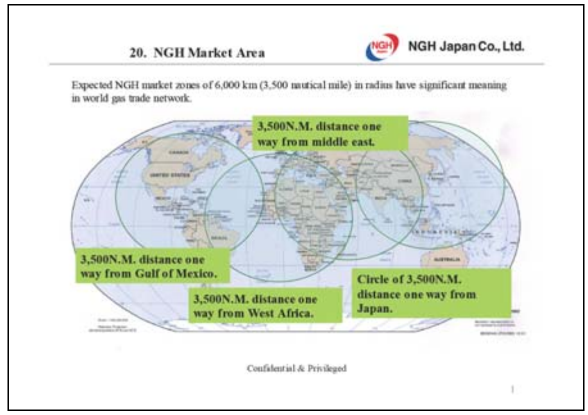

18. Cargo Demand NGH vs. LNG
NGH Japan Co., Ltd.
NGH has an advantage in transportation of medium size demand while LNG is suitable for big lot transportation. We consider there is the close point, as for cargo demand, around gas demand of 1.5 million tons per year.
High
CIF Gas cost
Low
NGH
LNG
NGH
LNG
Small lot
Large lot
0.01
0.1
1
10
Customer's gas demand (MMtpy)
Confidential & Privileged


19. Transportation Distance NGH vs. LNG
NGH Japan Co., Ltd.
As for transportation distance, NGH has an advantage in range of between 1,000 km and 6,000 km compared with other transport media.
1-2MMt (NG equivalent) ocean transportation CAPEX-DISTANCE portfolio
Project cost (CAPEX)
Pipeline
CNG
NGH
LNG
NGH
500 km
1,000 km
6,000 km
Distance to market
P/L
CNG
NGH
LNG
Confidential & Privileged


20. NGH Market Area
NGH Japan Co., Ltd.
Expected NGH market zones of 6,000 km (3,500 nautical mile) in radius have significant meaning in world gas trade network.
3,500N.M. distance one way from middle east.
3,500N.M. distance one way from Gulf of Mexico.
3,500N.M. distance one way from West Africa.
Circle of 3,500N.M. distance one way from Japan.
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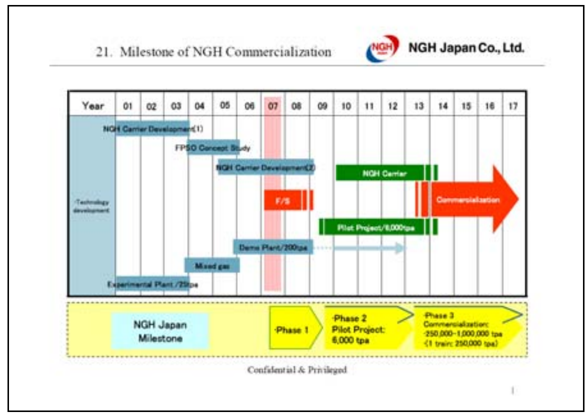
21. Milestone of NGH Commercialization
NGH Japan Co., Ltd.
Year
01
02
03
04
05
06
07
08
09
10
11
12
13
14
15
16
17
Technology development
NGH Carrier Development(1)
FPSO Concept Study
NGH Carrier Development(2)
NGH Carrier
F/S
Commercialization
Pilot Project/6,000tpa
Demo Plant/200tpa
Mixed gas
Experimental Plant /25tpa
NGH Japan Milestone
Phase 1
Phase 2 Pilot Project: 6,000 tpa
Phase 3 Commercialization: 250,000-1,000,000 tpa (1 train: 250,000 tpa)
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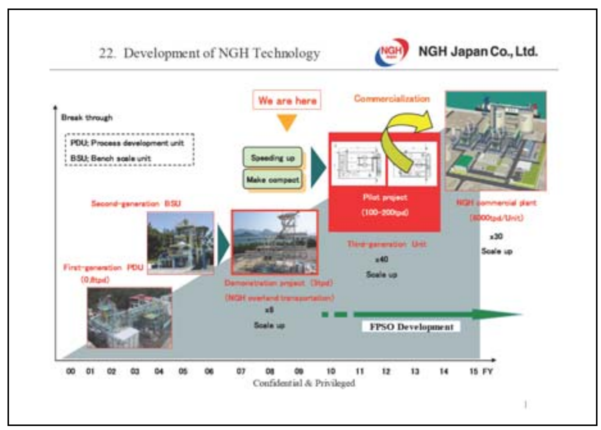
22. Development of NGH Technology
NGH Japan Co., Ltd.
Break through
PDU; Process development unit
BSU; Bench scale unit
We are here
Commercialization
Speeding up
Make compact
Second-generation BSU
First-generation PDU
Pilot project
(100-200tpd)
Third-generation Unit
x40
Scale up
NGH commercial plant
x30
Scale up
x5
Scale up
FPSO Development
00
01
02
03
04
05
06
07
08
09
10
11
12
13
14
15 FY
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23. Demo-Plant for NGH Land Transportation

NGH Japan Co., Ltd.

Demonstration plant
(Capacity of NGH 5 tons per day)
at LNG power station in Japan
(As of February 2008)

| 24

NGH Japan Co., Ltd.

Thank you

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5. Resource Assessment of Methane Hydrate in the Eastern Nankai Trough, Japan. T. Fujii, Japan Oil Gas and Metals National Corporation.

Resource Assessment of Methane Hydrate in the Eastern Nankai Trough, Japan

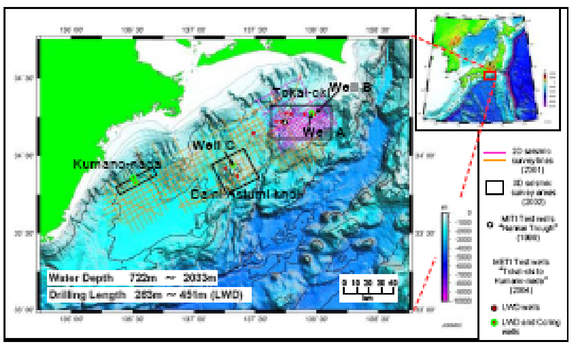
T. Fujii, T. Saeki, T. Kobayashi, T. Inamori, M. Hayashi, O. Takano, T. Takayama, T. Kawasaki, S. Nagakubo, M. Nakamizu and K. Yokoi
Japan Oil, Gas and Metals National Corporation (JOGMEC)

INTRODUMTION

Seismic data from the Nankai Trough, offshore central Japan, indicates widespread distribution of bottom simulating reflectors (BSR) that are interpreted to represent lower boundary of methane hydrate (MH) bearing zones. MH in the Nankai Trough is a potential natural gas resource, however, the volume, distribution, and occurrence of MH in this area is poorly understood. Resource assessment of MH in offshore Japan has been attempted intensively by several researchers in the past [1, 2]. However, precise assessment based on high density 2D/3D seismic survey data and well data had not been conducted.

Resource assessment of methane hydrate (MH) in the eastern Nankai Trough was conducted through probabilistic approach using 2D/3D seismic data and drilling survey data from METI exploratory test wells "Tokai-oki to Kumano-nada" [3, 4, 5, 6]. We have extracted more than 10 prospective "MH concentrated zones" [7, 8] characterized by high resistivity in well log, strong seismic reflectors, seismic high velocity, and turbidite deposit delineated by sedimentary facies analysis.

1 Survey Area (The eastern Nankai Trough)



2 Method

The amount of methane gas contained in MH bearing layers was calculated using volumetric method for each zone. Each parameter, such as gross rock volume (GRV), net-to-gross ratio (N/G), porosity (ϕ), MH pore saturation (Sh), cage occupancy, and volume ratio was given as probabilistic distribution for the Monte Carlo simulation, considering the uncertainly of these evaluations.

Volumetric Method (Gross Rock Volume Model) with Probabilistic Approach

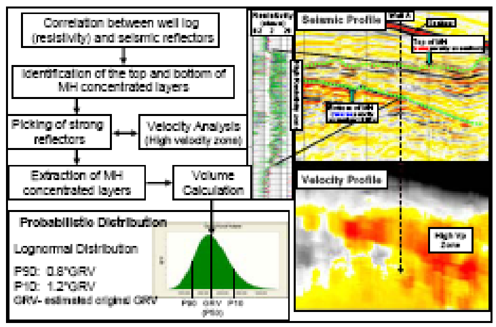
MH Resources (in place) = GRV × N/G × ϕ × S_h × VR × CO／28.3

Parameters		units	Data sources	
MH Resources (in place)		bcf	With well control	Without well control
GRV	Gross Rock Volume	MMm³	Strong Reflectors (top + bottom (BSR)) Seismic Velocity anomaly, Sand distribution (sedimentological interpretation)	
N/G	Net-Gross ratio	Frac.	Strong Reflectors + LWD Resistivity	Seismic Facies Map + Lithofacies column
ϕ	Porosity	Frac	LWD density log (Calibrated by core analysis)	LWD density + core analysis (vicinity wells)
S_h	MH Pore Saturation	Frac	LWD NMR and density log (Calibrated by PTCS gas dissociation test)	Relationship between Seismic velocity and MH saturation (vicinity wells)
VR	Volume Ratio	Frac	Basically 172 (0°C, 1atm)	
CO	Cage Occupancy	Frac	Basically 0.98 (Recent observations from natural samples)	
28.3	Conversion factor		1 bcf = 28.3 MMm³	

Software : Crystal Ball (Monte Carlo Simulation)

3 Gross Rock Volume (GRV) Estimation

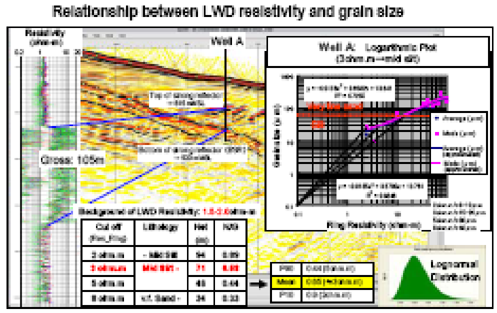
1. Strong seismic amplitude anomaly + velocity anomaly
2. Time-to-depth conversion: Interval velocity derived from Seismic Vision While Drilling (SVWD).
3. Risk factor was applied for the estimation of the GRV in 2D seismic area considering the uncertainty of seismic interpretation.



4 Net-to-Gross ratio (N/G) Estimation (1)

With Control Well:

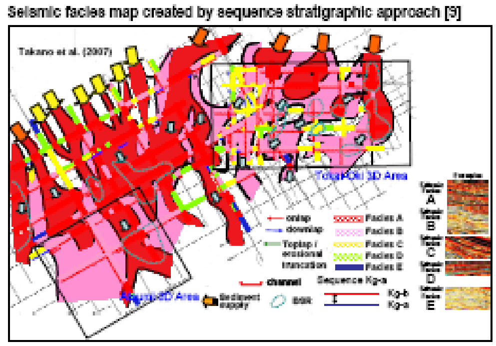
Relationship between LWD resistivity and grain size



5 Net-to-Gross ratio (N/G) Estimation (2)

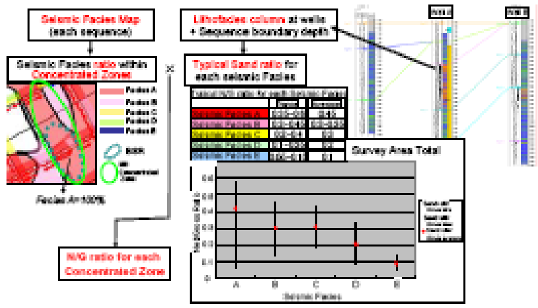
W/O Control Well

Seismic facies map created by sequence stratigraphic approach [9]



6 Net-to-Gross ratio (N/G) Estimation (2)

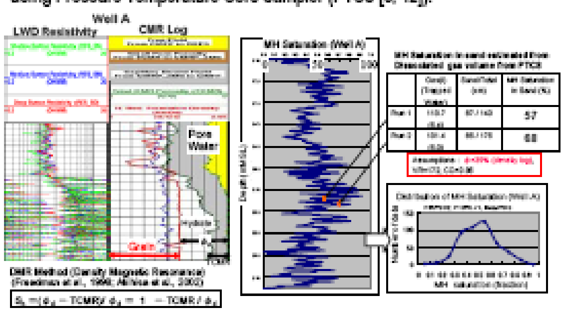
W/O Control Well



7 MH pore saturation (Sh) Estimation (1)

With Control Well

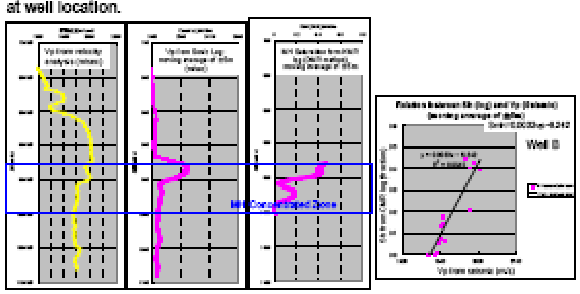
1. Combination of density log and NMR log (DMR method [10, 11])
2. Calibration by observed gas volume from onboard MH dissociation tests [4, 6] using Pressure Temperature Core Sampler (PTCS [3, 12]).



8 MH pore saturation (Sh) Estimation (2)

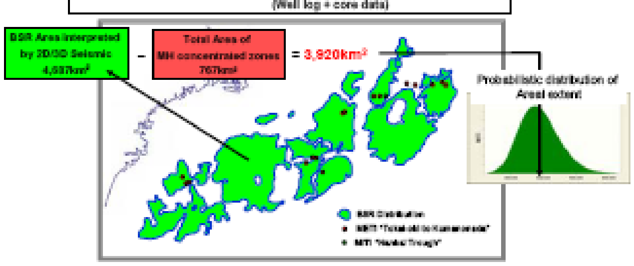
W/O Control Well

Relationship between seismic P-wave interval velocity and Sh from NMR log at well location.



9 MH bearing layers other than MH concentrated zones: BSR distribution

Volumetric Method (Area × Net Pay Model) with Probabilistic Approach
MH Resources (in place) = Area × Net Pay × ϕ × S_{MH} × VR × CO／28.3
(Well log + core data)



10 Results of Resource Assessment (Methane gas in place)

1. Total amount of methane gas in place : 40 tcf (Pmean).
2. Gas in place for MH concentrated zone: 20 tcf (Pmean) - Half of Total amount
3. 20 tcf also corresponds to the amount of methane in the eastern Nankai Tough (7000km²) evaluated by Satoh et al. (1996) [1].
4. 40 tcf corresponds to 14 years annual consumption of natural gas in Japan (2.9tcf, BP statistical review in 2005).
5. Areal extent of BSR in our study in the eastern Nankai Trough (4,687km²) occupied only about 10% of assumed whole BSR of offshore Japan (51,600km2) [2].

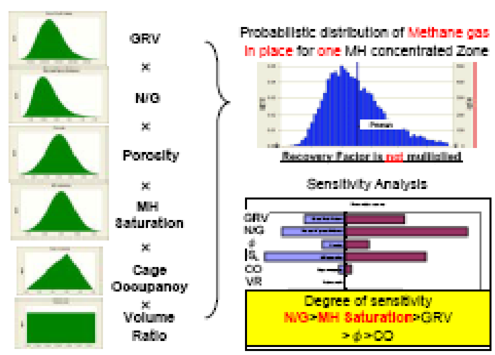
Category		Parameters (Total/average)						MH Resource in place		
		GRV (MMm³)	N/G (frac.)	ϕ (frac.)	S_{MH} (frac.)	VR (frac.)	CO (frac.)	P90 (tcf)	P10 (tcf)	P_{mean} (tcf)
MH Concentrated Layer	With Well Control	4,455	0.36	0.43	0.52	172	0.95	1,420	4,838	2,961
	W/O Well Control	34,931	0.37	0.45	0.51	172	0.95	4,829	34,553	17,318
	Total	39,386	0.37	0.44	0.51	172	0.95	6,250	39,391	20,279
MH Bearing Layer		Area 3920km²	Net pay 6.4m	0.48	0.29	172	0.95	3,772	43,139	20,056
		1,254,400 MMm³	0.02							
Total								10,021	82,529	40,335

GRV: Gross Rock Volume, N/G: Net to Gross ratio, ϕ: porosity, S_{MH}: hydrate pore saturation, VR: Volume Ratio, CO: Cage Occupancy

With Well Control: MH Concentrated layers confirmed by Well data
W/O (without) Well Control: MH Concentrated layer suggested from 2D/3D Seismic data

Annual consumption of natural gas in Japan (2005): 0.082Tcm= 2.9Tcf
(BP Statistical Review)

11 Example of Probabilistic Distribution and Sensitivity Analysis



CONCLUSIONS

Total amount of methane gas in place contained in MH within survey area in the eastern Nankai Trough was estimated to be 40 tcf as Pmean (average) value (P90: 10 tcf, P10: 83 tcf). Total gas in place for MH concentrated zone was estimated to be 20 tcf (Half of total amount) as Pmean value(P90: 6.3 tcf, P10: 39 tcf) . Sensitivity analysis indicated that the N/G and Sh have higher sensitivity than other parameters, and they are important for further detail analysis.

ACKNOWLEDGEMENTS

Drilling of the METI "Tokai-oki to Kumano-nada" wells was planned and financed by METI (Ministry of Economy, Trade and Industry). The methane hydrate research program has been carried out by the MH21 research consortium consisting of JOGMEC, AIST, and ENAA, with financial support from METI. The domestic survey team of JOGMEC managed the well drilling exercises.
We would like to thank METI and JOGMEC for providing permission to publish this report.

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[1] Satoh et al. (1996): Jour. Geol. Soc. Japan, Vol.102, No.11, p.959-971, November 1996 (in Japanese with English abstract).
[2] Satoh, M. (2002): Proceedings of the Forth International Conference on Gas Hydrates, Yokohama, p175-178.
[3] Takahashi et al. (2005): Proceedings of 2005 Offshore Technology Conference, Houston, Texas, U.S.A. (OTC17162).
[4] Fujii et al. (2005): Proceedings of the Fifth International Conference on Gas Hydrates,Trondheim, Norway, Vol.3, p. 974-979
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[6] Fujii et al. (2008): Collett, T., Johnson, A., Knapp, C., and R.Boswell, eds, AAPG Special Publication, 2008 (in press).
[7] Saeki et al. (2008): Proceedings of 2008 Offshore Technology Conference, Houston, Texas, U.S.A. (OTC19311).
[8] Fujii et al. (2008): Proceedings of 2008 Offshore Technology Conference, Houston, Texas, U.S.A. (OTC19310).
[9] Takano et al.(2007): Abstracts of Japan Geoscience Union Meeting 2007, Makuhari, Japan,G120-006.
[10] Freedman et al.(1998): Paper II, presented at 39th SPWLA Symposium, 1998.
[11] Akihisa et al. (2002): SPWLA 43rd Annual Logging Symposium, Oiso, Japan, 2002, Paper BB.
[12] Kawasaki et al. (2007): Journal of the Japanese Association for Petroleum Technology, vol.71, no.1, 2007, p139-147

B. Breakout Sessions

1. Characteristics of hydrate in marine sediments and commercial value of hydrate.

Session Chair: Warren Wood

Suggested Topics:

What are the present limitations, and corresponding challenges, in our understanding of the dynamics of marine hydrates in porous media?

How can we best bridge the knowledge gaps so as to improve our abilities to quantify the commercial value of different marine hydrate occurences in terms of hydrocarbon distribution and feasible exploitation schemes?

Alternative approaches for in situ conversion to energy and/or other products?

International priorities and possibilities for funding international research collaboration.

Overview of Discussions

Characteristics of hydrate in marine sediments and commercial value of hydrate
WHAT DO WE NEED

How do hydrates form in sediments?
Fine – coarse grained
Water in gas a problem for production?
Dissociation around heat pipes spacing, heat input
Challenges – Looking in the wrong places?
Need to find good reservoirs. Challenge is to geophysics or geologists. Go for sands
Predict from sesimic profiles – build geological – hydrocarbon model. Include possible sands slumped from shelf edge. Prospecting?
What concentration threshold is required for commercial viablilty. Production rate is also crucial.
Activities need to be
1) profit driven (eg oil shale, tar sands)
And/Or
2) Nurtured by govt. Or research community
Is each occurence of hydrate unique? Hydrate formations are significantly undersampled. (how do clays and other environmental factors affect hydrate concentration, potentia for flow, etc)
How do soils frature pnumatically
What are the effect of grouting and other production activites
Production requires melting – how do we do this? Heat? Chemistry? Pressure?
Improved rock physics models with hydrates. Lithology and frequency dependent, perhaps also anisotropic
CSEM joint with seismic – simultaneous modeling and inversion

- Achieving goals
- Start by looking at hydrates that are auxilary to conventional fields- gain experience with reduced risk
- Production Modeling needs improvement
- Look where we have existing infrastructure (e.g. Petrobras and other deep water operators)
- Data from shallow sections logs and seismic
- Can these be acquired and released at minimal cost?
- Look at old data in new ways (resistivity)
- Develop and use new technology – pressure cores
- Higher resolution data
- Use geohazard data better

- In Situ energy

- How can energy be used locally to enhance recovery or profit
- Fuel cells on the sea floor (seafloor battery)
- Convert methane to carbon and hydrogen
- Rates are a limiting factor
- CO2 sequestraion, political pressure forms economic pressure in the form of carbon credits.

Take away

- Need access to Higher resolution seismic (3D)
- Production rates as well as volumes
- Improved production models (include hole maintenance, flow assurance through stability field, enhanced recovery)
- Exploration and geologic models that include shallow seismic and logs

- International Priorities

- Systematic excercise in comparing regions.
- Globalization of analyses. Databases holding raw and analyzed data from drilling, seismic etc. Very few data sets presently
- Data sharing between countries and companies. Most hydrtate programs are national or driven by national needs.
- Reduce risk of loss for oil companies sharing data
- Collaborations like JIP govt and industry (e.g. seismic exploration is dominated by industry – what would it take to share? Pressure core technology developed largely by EU.
- Political leadership

2. Methane hydrate fluxes from the ocean and potential climate implications.

Session Chair: Jens Greinert

Suggested Topics:

What are the impacts of natual methane flux on climate change?

What is the temporal and spatial variability of methane flux to the atmosphere?

What is the impact of climate change on global economy?

What is the contribution of methane to ocean carbon modeling?

How do we model methane contribution to climate change?

Overview of Discussions
Breakout Session B: Methane hydrate fluxes from the ocean and potential climate implications.

Key Points:

1. Bubble vs dissolved flux for water column input. Breakout bubble dissolution relative to atmospheric input.
   a. Consideration of bubble transport distance (water column depth), bubble gas concentration, chemical outer shell coating, water column methane concentrations, water column methane turnover, water column salinity and temperature is necessary.
   b. Need modeling to determine the key parameters to predict the methane fate water column vs. atmosphere.
   c. Model will include total cycling relative to grazing, nutrient mineralization.

2. Basic focus in water column vs. atmosphere methane flux. This needs to be quantified.
   a. Set transport water column vs. atmosphere in vertical line near shore to offshore. Include methane concentrations in the water column and concentrations caught in water column-atmosphere gas trap.
   b. Compare trends for constant flow vs. random/high flux features.
   c. Does tidal variation or current circulation change these profiles?
   d. Set spatial region in locations that are stable temperature vs. changing temperature for predictions of climate change impact.
   e. Couple these surveys with the Greinert sediment hydroacoustic profiler.

3. Need an environmental assessment that incorporates modeling and field work in the current Arctic to predict future methane flux and the contribution of methane to the climate change.
   a. Need to set the limits for impact of methane on atmosphere as a function of water column depth. This needs fieldwork. This focus is set with the thought that methane flux is not significant at a water column depth of 200 m and greater.
   b. Studies focus on continental margin stability controlled by carbonate formation via methane oxidation.
   c. Methane contributions to carbon cycling in sediment and water column.
   d. We need some thorough spatial survey of the in situ methane turnover.

Summary:

1. Need general ocean model to (GCM) to include methane input. This would include seasonal forcing, bubble dissolution. This could use the Gulf of Mexico model and transition to Arctic. This would need a combination of modeling, geochemistry, satellite imaging, and physical oceanography.

2. Need fieldwork to set depth of concern for the methane flux to water column vs. atmosphere. This would contribute to the methane carbon cycling in the water column. Need thorough breakout of dissolved and gas phase cycling from sediment to the water column in different water columns with consideration of depths, meso-scale eddies, temperature profiles, etc.

Participants

NAME	AFFILIATION
N. Langhorne	ONR Global
G. Nihous	University of Hawaii
Y. F. Chen	Geological Survey of Norway
H. Haflidason	University of Bergen
T. Treude	IFM-GEOMAR Kiel, Germany
E. Vaular	University of Bergen
R. Baker	US DOE-NETL
L. Hamdan	NRL
P. Jackson	British Geological Survey
A. Lemon	University of Leicester
E. Allison	US DOE-DC
R. Coffin	NRL
J. Greinert	University of Ghent

Session C: Laboratory and pilot scale experiments

Session Chair: James Howard

Suggested Topics:

Can we design realistic laboratory experiments which can be representative of real systems that have developed over geological time scales?

What are the available monitoring techniques and what are the corresponding limitations?

Is there a need for controlled pilot scale experiments on artificially constructed formations? And if so - how should these be constructed?

Can experimental studies or pilot plant studies provide also a realistic enough platform for development of exploitation technologies and related special "arctic" challenges?

Experiments related to infrastructure, with special focus on transport and storage.

Overview of Discussions

Laboratory and Pilot-Scale Experiments

Breakout Session C
Fiery Ice – 6
Bergen
14 Mai 2008

Experimental Parameters That Must Be Considered

Common Parameters

- Temperatures (Heat Flow….)
- Pressures
- Compositions (Liquids, Gases, Interfaces)
- Sediment Properties (Mineralogy, Size, …)
- Elastic Parameters

Questions for Breakout Session C

- Can we design realistic laboratory experiments that represent "real" geological systems?
- What are available monitoring systems – and their limitations?
- Are controlled pilot-scale measurements needed? On artificial samples?
- Can laboratory or pilot-scale studies provide realistic data for field development, especially in the Artic?
- Are there unique experiments for transport and storage issues associated with hydrates?

Realistic (?) Experiments

What Defines "Realistic"

- Lab vs. "Pilot"
  - Homogeneous vs. Heterogeneous
  - Size of Pilot Can Vary
  - Time? Geological vs. Engineering
- Limitations to Realism, but Still Important for Critical Data Used in Field-Scale Evaluations.

Major Areas of Experiments

- Geological Accumulation
- Production Testing
- Geo-Mechanics
- Bio-Geochemistry
- Thermodynamics

Experiment Monitoring

Laboratory to the Field

- Multiple Measurements of Parameter (Transport Properties….)
- Imaging
  - CT-XRay, MRI, IR
  - Sample-Size Limitations
- 4-D Monitoring of Processes
  - Seismic, Electromagnetic, Geomechanical
  - Access, Signal/Noise

Laboratory “Pilot-Scale”

Bigger than a Benchtop

- Potential Experiments
  - Hydrate Accumulation, Well-bore Stability
- Limitations:
  - Does “Artificial” Capture Key Properties?
  - Boundary Conditions
  - Temperature Control
  - Cost
- Is There A Need?
  - Some Experiments Can Stay Small

Infrastructure Experiments

- Yes – Needed and Being Done.
  - Flow in Pipes
  - Storage and Transport

Realistic Data for Exploitation

- Production Scenarios Only
- Lab Experiments Useful for Understanding Some Fundamental Properties, but the Field-Scale Experiments are Necessary for Production Planning (Simulator Inputs).
- Single-Well Tests Will Play Critical Role in Field Planning.

V. Plenary Session 2: Arctic Hydrates

A. Invited Speakers

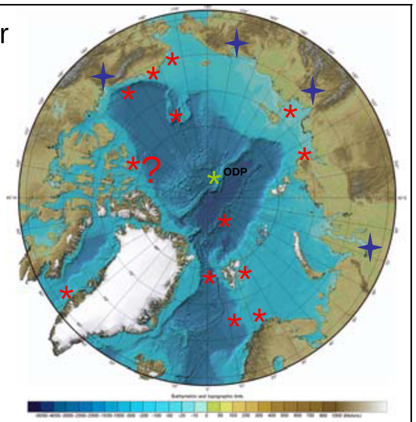
1. Research Planning in the Arctic Ocean. Richard Coffin, US Naval Research Laboratory

International Collaboration on Arctic Ocean Research

Richard Coffin
Marine Biogeochemistry Section
NRL Code 6114

http://www.marum.de/Meeresbodenbohrgeraet_MeBo.html

Regions for Research Focus



Rationale

6th IMHRD – Arctic Ocean

- Gulf of Mexico: 1998-2007; US, Japan, Canada, South Africa
- Haakon Mosby Mud Volcano: 1998; Russia, US, Norway, Germany
- Mid Chilean Margin: 2003, 2005; Chile, Japan, Germany, Canada, US
- Hikurangi Margin: 2006; New Zealand, US, Canada, Germany

Data collection methods

- Long term sediment monitoring
- Long term water column monitoring
- Satellite imaging
- Seismics, CSEM, heatflow
- Seafloor morphology
- Gravity and piston coring
- CTD
- Long term water column buoys

Key Program Topics

- Energy
- Climate change
- Global Warming
- Tundra vs Ocean methane flux
- Variation and changes in optical and acoustic signatures (USN, others)
- ***Long term monitoring***, amphibic

International Funding

- NOAA
- ONR
- EU
- ESF
- NSF
- Ship time

Need to mix funds.
Where do we go?

FY08, FY09 ONR 3 mil USD, NOAA 2 mil USD

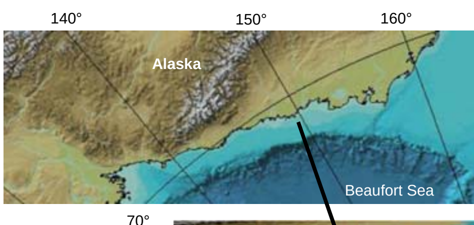
Current Arctic Planning

Current Planning
- NRL – Coffin, Hamdan, Wood
- Heriot-Watt – Pecher
- U. Ghent/NIOZ – Greinert
- U. Hawaii – Masutani, Nihous
- IFM-GEOMAR – T. Treude
- NOAA

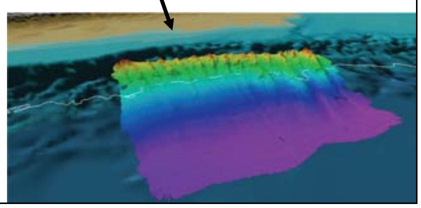
Research Focus

- Climate change/global warming
- Methane hydrate exploration
- Coastal carbon cycling, e.g., sediment methane vs. tundra carbon flux
- Biotic vs. abiotic carbon cycling
- Coastal ocean carbon modeling

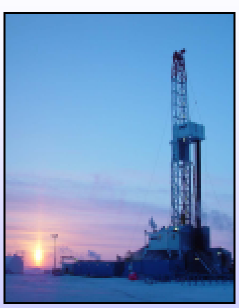
Summer 2009, 2010 Planning



NRL, UH
NOAA, NETL
University of Ghent
Heriot-Watt University
U. Alaska



2. Overview of Research Plans and Accomplishments for the United States. Edith Allison, US Department of Energy



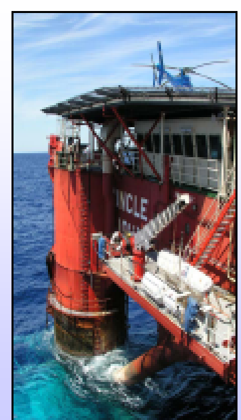
Update on U.S. Methane Hydrate R&D

6th International Workshop on Methane Hydrate Research and Development

Presented by
Edith Allison
U. S. Department of Energy

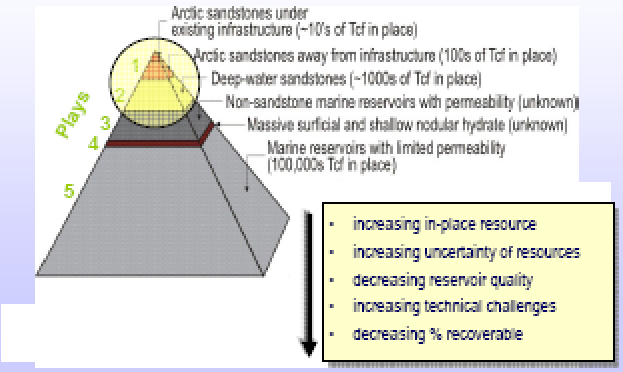
The U.S. National Gas Hydrates R&D Program

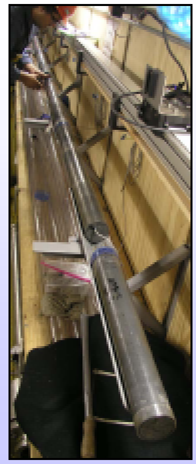
- Begun in 1997
- By 2025, deliver the science and technology needed to
  - realize the resource potential of gas hydrates
  - understand gas hydrate's role in the natural environment, *while...*
  - supporting the training of future energy scientists
  - building international collaborations
- DOE works with US Geological Survey, Minerals Management Service, Bureau of Land Management, National Oceanic and Atmospheric Administration, National Science Foundation, and Naval Research Lab



U. S. Department of Energy

Gas Hydrates Resources



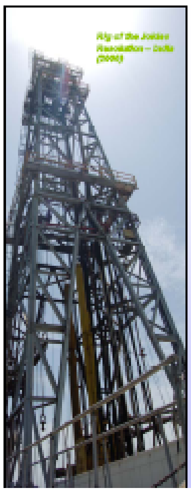


Marine Gas Hydrates

Gulf of Mexico Joint Industry Project

- Broad Consortium
  - Government *(DOE, USGS, MMS)*
  - Industry *(Chevron, CP, Schlumberger, Halliburton, AOA geophysics)*
  - Academia *(Rice, Ga. Tech, Scripps)*
  - International *(KNOC (Korea), Reliance (India), JOGMEC (Japan))*
- Tool Developments
  - New Seismic Inversion techniques
  - New coring devices under development
  - New core analysis equipment
- Field Expeditions
  - Spring 2005: GH-hazards & fine-grained sediments
  - Spring 2008: LWD exploratory cruise of GH in sand
  - 2009?: Coring GH in sandy sediments

U. S. Department of Energy



R&D Priorities

Gas Hydrates as a Resource

- Leverage fundamental science efforts
- Understand the environmental implications
- Develop reliable exploration technologies (pre-drill detection and characterization)
- Conduct marine investigations to assess/confirm the resource
- Conduct a series of long-term production tests
- Develop numerical modeling capability

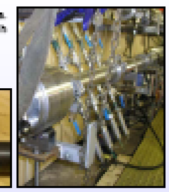
U. S. Department of Energy

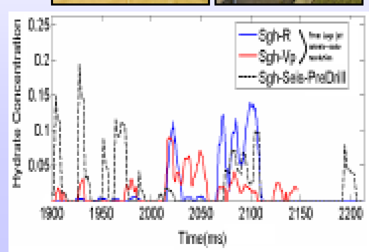
JIP 2005 Expedition

- **Advances in pressure core collection and analysis**
- **Subsurface fine-sediment hydrate poses a minimal drilling hazard (low likely S_{gh})**
- **Potential for viable remote detection & quantification of marine hydrates confirmed**

New P-corer, based on PTCS

IPTC – Ga. Tech

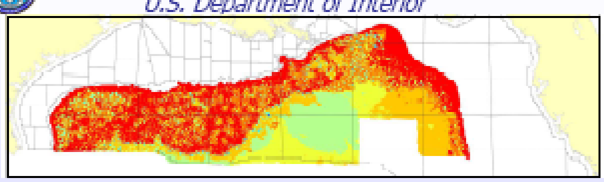




Marine Gas Hydrate Assessment

U.S. Department of Interior

USGS



Courtesy: U.S. Minerals Management Service

- In-place model developed for the GoM
  - 400,000 km² of seismic data
  - 1000-trial Monte Carlo over 200,000 grid cells
- Calculates sediment volume in Hydrate Stability Zone
  - Bathymetry
  - Sediment thickness to top salt
  - Vertical sand percent
  - Surficial seismic anomalies
  - geological-based depsystem interpretations
- Available methane calculated from biogenic gas generation, migration models

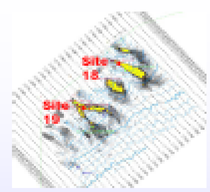
Mean hydrate in-place:
607 TCM
(21,444 TCF)
Mean volume in sandstones:
190 TCM
(6,717 TCF)

U. S. Department of Energy

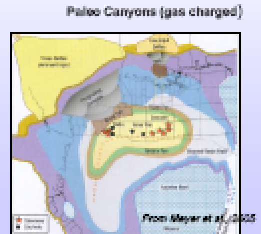
JIP 2008 Expedition

Late Spring

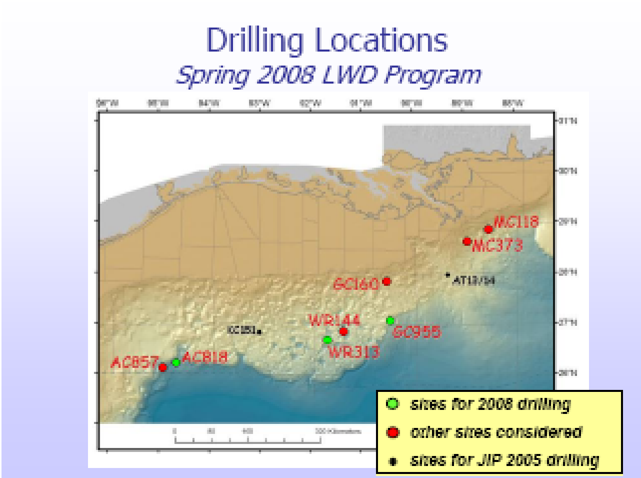
- Expedition design
  - explore potential for hydrate-charged reservoir-quality sand
  - multi-site LWD expedition
  - subsequent coring leg (2009?)
- Objectives
  - high-grade sites for later coring
  - calibration of seismic techniques for GH detection
  - test alternative exploration models
  - inform the MMS in-place assessment

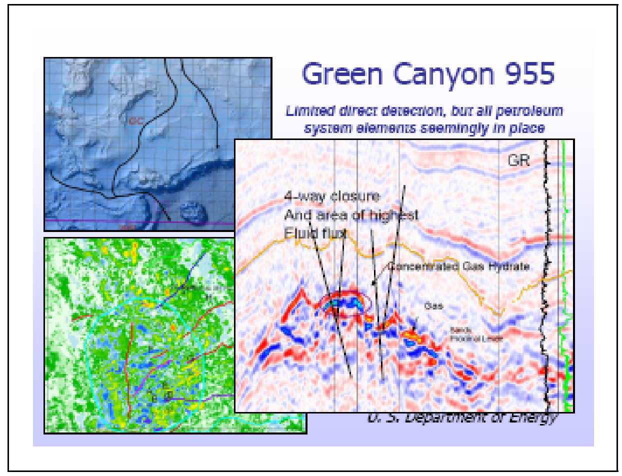


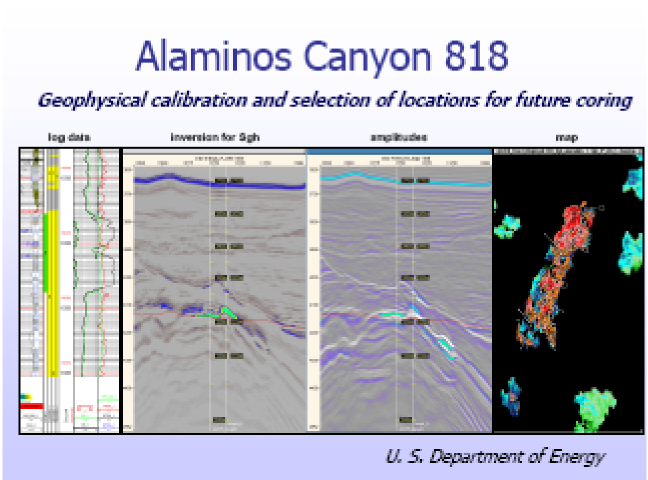
Paleo Canyons (gas charged)

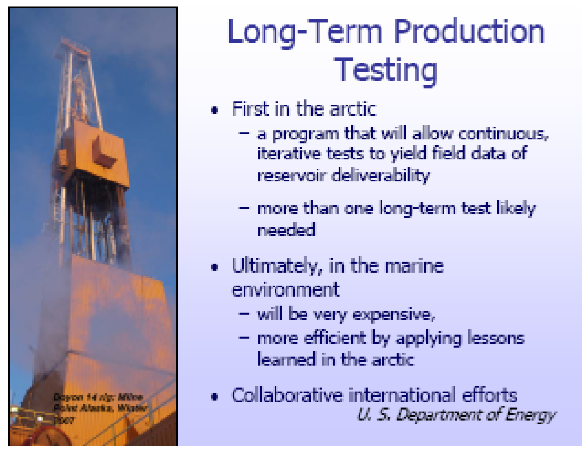


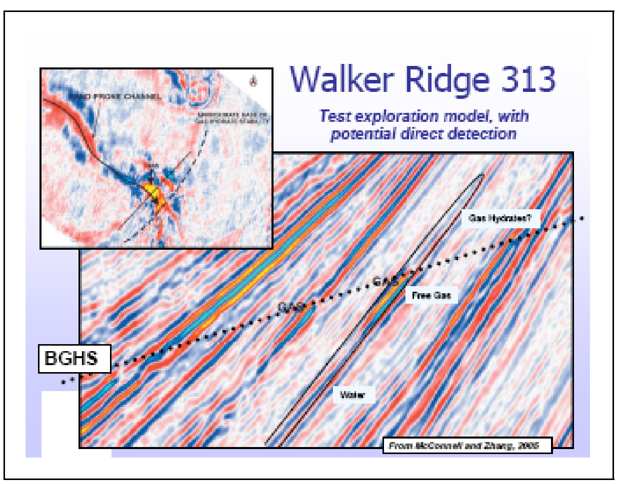
U. S. Department of Energy


Drilling Locations
Spring 2008 LWD Program
MC118
MC373
GC160
AT13/14
WR144
GC955
WR313
AC857
AC818
KC151
sites for 2008 drilling
other sites considered
sites for JIP 2005 drilling


Green Canyon 955
Limited direct detection, but all petroleum system elements seemingly in place
GR
4-way closure
And area of highest
Fluid flux
Concentrated Gas Hydrate
Gas
U. S. Department of Energy


Alaminos Canyon 818
Geophysical calibration and selection of locations for future coring
log data
inversion for Sgh
amplitudes
map
U. S. Department of Energy

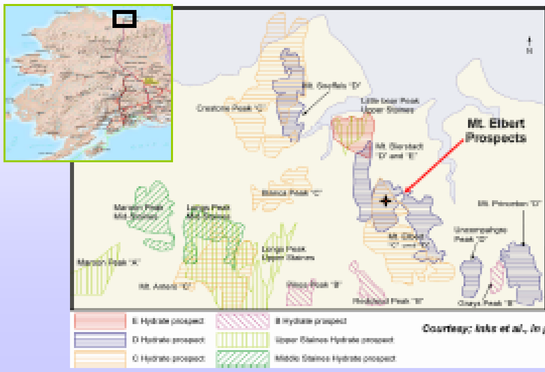

Long-Term Production Testing
• First in the arctic
– a program that will allow continuous, iterative tests to yield field data of reservoir deliverability
– more than one long-term test likely needed
• Ultimately, in the marine environment
– will be very expensive,
– more efficient by applying lessons learned in the arctic
• Collaborative international efforts
U. S. Department of Energy


Walker Ridge 313
Test exploration model, with potential direct detection
Gas Hydrates?
GAS
Free Gas
Water
BGHS
From McConnell and Zhang, 2005


Mt. Elbert Test Well
Field Operations, February 3-19 2007
BP, USGS, DOE-NETL, Omni Laboratories, Mi-Swaco, Drill-Cool,
Doyon Drilling, Schlumberger, Interpretation Services, Inc.,
Ryder Scott Company, RPS Energy, ASRC Energy Services, Reed Hycalog,
Oregon State University, U. Alaska-Fairbanks, U. Arizona

Phase 1: Prospecting

14 discreet gas hydrate accumulations identified in Milne Point Unit



Field Operations

Wireline coring

- Outstanding Performance of Corion wireline-retrievable system
  - Oil-based mud; chilled to ~30° F
  - 504' of cored with 85% recovery
- 261 subsamples obtained
  - 7 samples in liquid nitrogen
  - 4 samples in pressure vessels
  - 52 for physical properties
  - 46 for porewater geochemistry
  - 5 for thermal properties
  - 86 for microbiology
  - 46 for organic geochemistry
  - 15 for petrophysics
- Recipients:
  - NETL, LBNL, PNNL, ORNL, CSM, NRCan, USGS, CP, OSU, Omni Labs

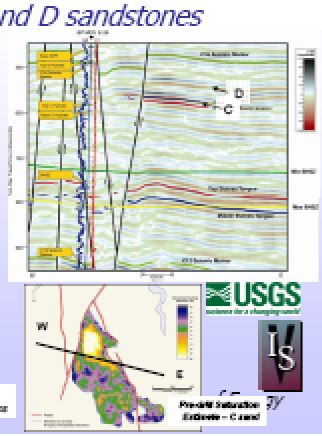
U. S. Department of Energy

Phase 2: Delineation/Evaluation

"Mt. Elbert" C and D sandstones

- Prospects occur in an undrilled, fault-bounded trap
- Seismic attributes used to estimate reservoir thickness and saturation for two prospective zones:
  - An upper "D" sand: 46' thick with 68% Sgh
  - The "C" sand: 70' thick with 85% Sgh

Courtesy; Inks, T., Lee, M., Taylor, D., Agena, W., Collett, T. and R. Hunter, in press



Mount Elbert MDT Results

- Confirmation of gas release via depressurization
- Clear indication that depressurization alone may not be sufficient in select (T) settings
- Confirmation of mobile water phase
  - Sgh = 65%; 25% = Swirr
  - Sgh = 75%; 10% = Swirr
- Determination of intrinsic K
  - 0.12 – 0.17 mD
- Reformation kinetics may be important
- Detailed reservoir heterogeneity may control productivity

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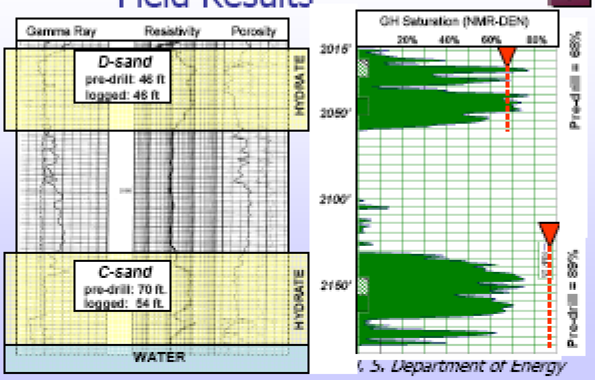
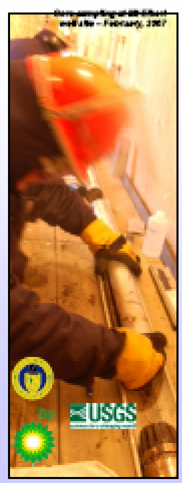
Pre-drill Prediction vs Field Results



U. S. Department of Energy

Mt Elbert Gas Hydrate Well Summary



- Demonstrated safe collection of data in shallow unconsolidated, GH-bearing sediments
  - good hole = outstanding core recovery and log suite
- Confirmed GH reservoir in close conformance to pre-drill predictions
  - ability to prospect for hydrate using G&G approach
  - improved confidence in broader ANS GH resource assessment
- Coring, Logging, Pressure Testing Program
  - fully integrated data and sample set
  - moveable fluids in fully-saturated reservoirs quantified and accessed
  - gas release via depressurization -

U. S. Department of Energy

Milne Pt, Alaska, Feb. 2007

2010 Production Test
Site Selection Parameters

- Location that allows continuous, long-term access for as long as necessary
- Designed to provide the best data for determining the potential productivity of gas hydrate reservoirs
  - Maximize the science, not necessarily the rate
- Minimize impact on existing operations
- Manage risk: operationally simple, with best reservoir conditions
- Learn from others – Mallik

U. S. Department of Energy

Research on Environmental Impacts of Methane Hydrate

Issues:
- Methane hydrate captures microbial and thermogenic methane, keeping it from reaching the ocean and atmosphere
- Methane may be released from hydrate as ocean waters and permafrost warm

Research:
- Past warming events: temperature increased before atmospheric methane rose
- Isotope analysis of source of methane inclusions in ice cores - hydrate, terrestrial?
- Microbial methane production rates
- Fate of methane in the ocean column

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International Comparison Study
Of five leading gas hydrate reservoir simulators

Problems of increasing complexity:
1. Base Case - 1D, closed system
2. Base Case + Hydrate
3. 1D (Cartesian) Production
4. 1D (radial) Production
5. 2D Production
6. History Matching - Alaska MDT test
7. Production Scenarios
   1. Mt. Elbert-like
   2. Prudhoe Bay L-Pad
   3. Formation near base HSZ

- Simulators:
  - STARS
  - Tough+/Hydrate
  - HRS
  - MH21
  - STOMP-Hydrate
- Public website with problems, results, and analysis:
- *www.netl.doe.gov/methanehydrates*

U. S. Department of Energy

3. USGS Methane Hydrate Research Activities, Thomas Lorenson, US Geological Survey

USGS Gas Hydrates Project Overview

International Workshop on Methane Hydrate R&D

14 May, 2008

USGS

Three Regions
Five Teams
Two Programs
One Discipline
Many Collaborators

Denver
Warren Agena
Tim Collett
Myung Lee
John Miller
Vacancy-Sci.
Vacancy-Ops
Tanya Inks

Menlo Park
Tom Lorenson
Pat Hart
Steve Kirby
Laura Stern
John Pinkston
Students

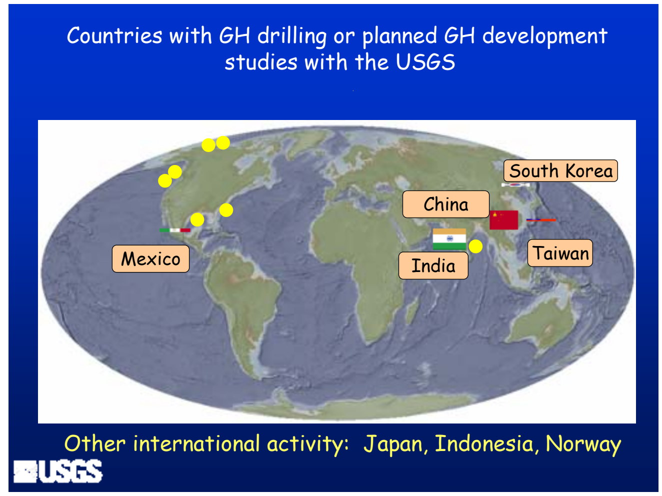
Woods Hole
VeeAnn Cross
Dave Foster
Debbie Hutchinson
Dave Mason
John Pohlman
Carolyn Ruppel
Dave Twichell
Bill Winters
Bill Waite

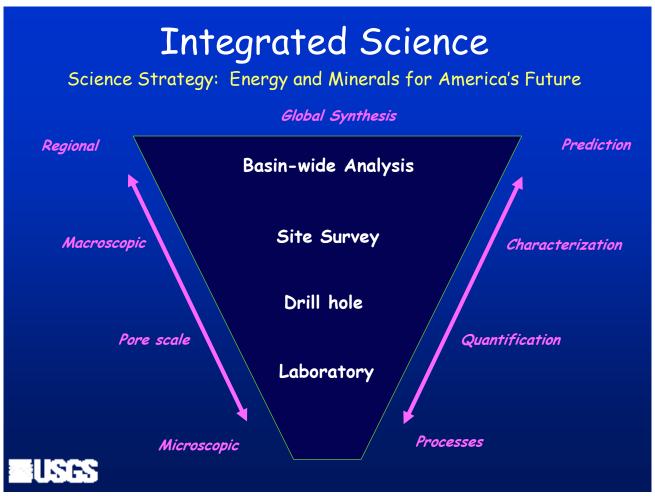
Reston
I-Ming Chou

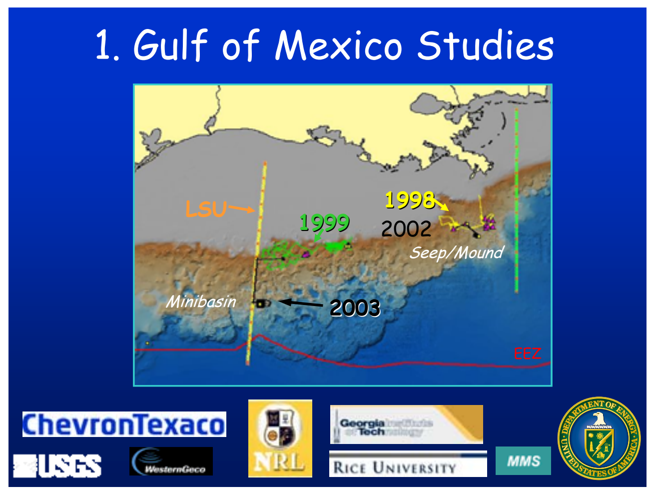
CMGP ERP

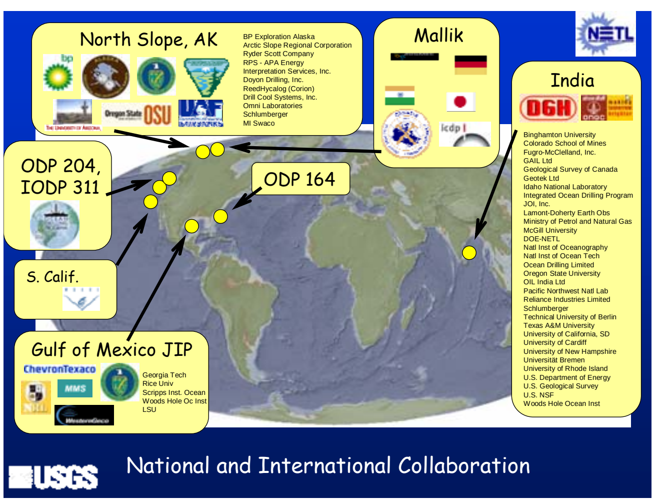
USGS

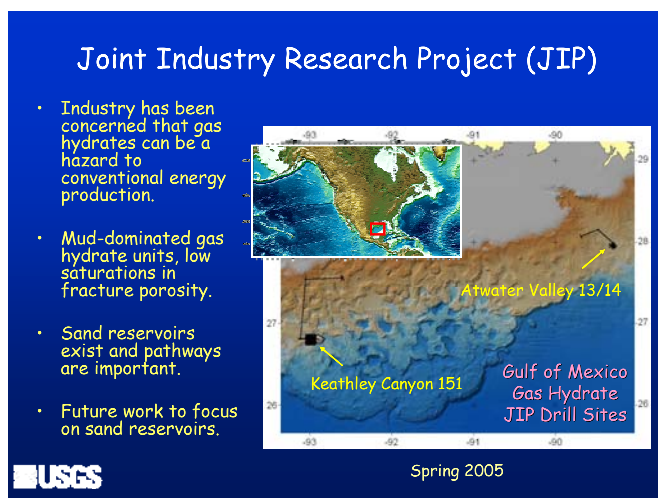

Goal of Project
5-year plan
Understand the geology of natural gas hydrates in marine and permafrost environments
USGS

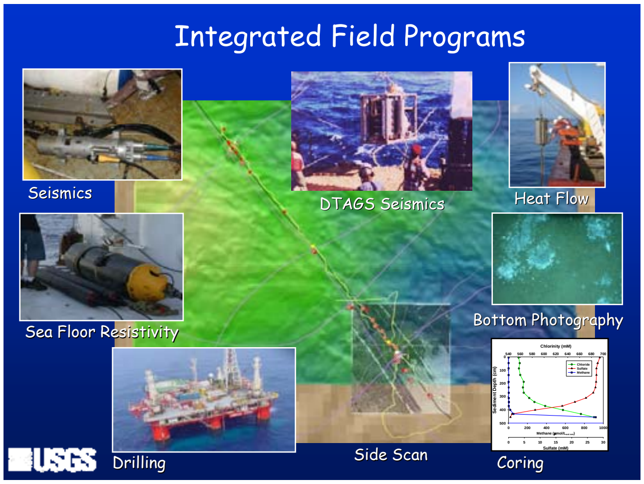

Countries with GH drilling or planned GH development studies with the USGS
South Korea
China
Mexico
India
Taiwan
Other international activity: Japan, Indonesia, Norway
USGS

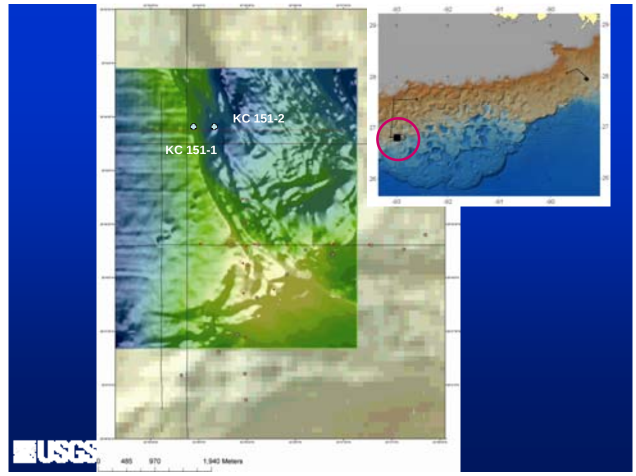

Integrated Science
Science Strategy: Energy and Minerals for America's Future
Global Synthesis
Regional
Prediction
Basin-wide Analysis
Macroscopic
Characterization
Site Survey
Drill hole
Pore scale
Quantification
Laboratory
Microscopic
Processes
USGS

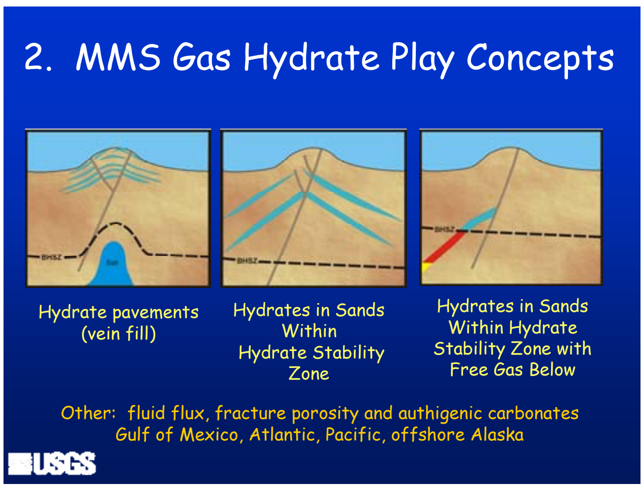

1. Gulf of Mexico Studies
LSU
1999
1998
2002
Seep/Mound
Minibasin
2003
EEZ
ChevronTexaco
NRL
Georgia Tech
Rice University
MMS
USGS
WesternGeco

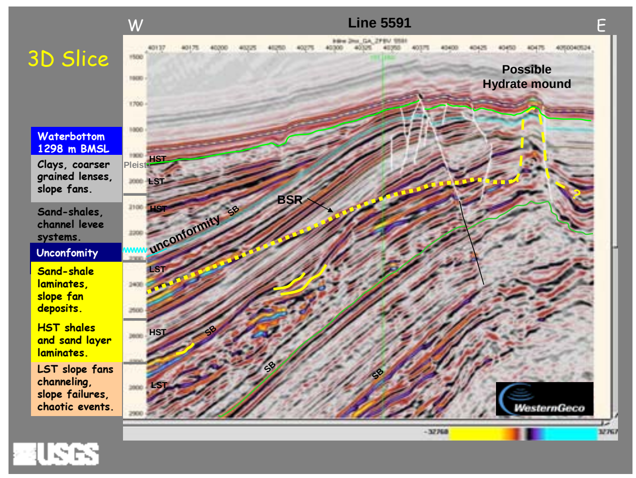

North Slope, AK
Mallik
NETL
India
ODP 204, IODP 311
ODP 164
S. Calif.
Gulf of Mexico JIP
ChevronTexaco
MMS
Georgia Tech
Rice Univ
Scripps Inst. Ocean
Woods Hole Oc Inst
LSU
National and International Collaboration
USGS

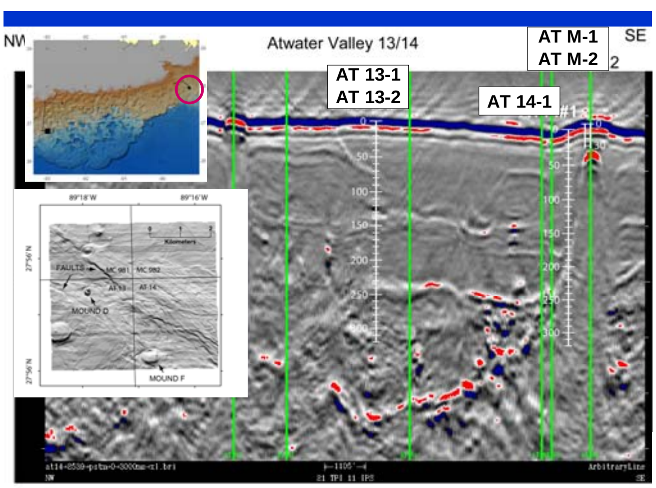

Joint Industry Research Project (JIP)
Industry has been concerned that gas hydrates can be a hazard to conventional energy production.
Mud-dominated gas hydrate units, low saturations in fracture porosity.
Sand reservoirs exist and pathways are important.
Future work to focus on sand reservoirs.
Atwater Valley 13/14
Keathley Canyon 151
Gulf of Mexico Gas Hydrate JIP Drill Sites
Spring 2005
USGS

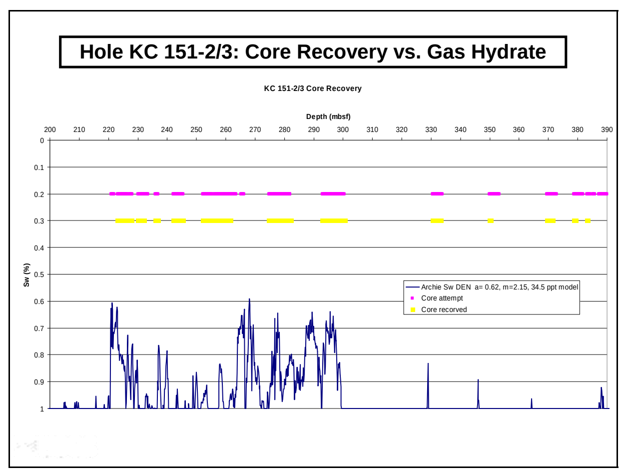

Integrated Field Programs
Seismics
DTAGS Seismics
Heat Flow
Sea Floor Resistivity
Bottom Photography
Drilling
Side Scan
Coring
USGS


KC 151-2
KC 151-1
USGS


2. MMS Gas Hydrate Play Concepts
Hydrate pavements
(vein fill)
Hydrates in Sands
Within
Hydrate Stability
Zone
Hydrates in Sands
Within Hydrate
Stability Zone with
Free Gas Below
Other: fluid flux, fracture porosity and authigenic carbonates
Gulf of Mexico, Atlantic, Pacific, offshore Alaska
USGS


W
Line 5591
E
3D Slice
Possible
Hydrate mound
Waterbottom
1298 m BMSL
Clays, coarser grained lenses, slope fans.
Sand-shales, channel levee systems.
Unconfomity
Sand-shale laminates, slope fan deposits.
HST shales and sand layer laminates.
LST slope fans channeling, slope failures, chaotic events.
BSR
unconformity
WesternGeco
USGS


Atwater Valley 13/14
AT M-1
AT M-2
AT 13-1
AT 13-2
AT 14-1
SE


Hole KC 151-2/3: Core Recovery vs. Gas Hydrate
KC 151-2/3 Core Recovery
Depth (mbsf)
Sw (%)
Archie Sw DEN a= 0.62, m=2.15, 34.5 ppt model
Core attempt
Core recovered

JIP Geochem Results

- Low gas hydrate saturation
- Hydrocarbon gas is mainly of microbial origin
- Possible secondary methane from anerobic petroleum oxidation
- Future drilling should target thermogenic hydrate

USGS

Lease Block No.	AC818	GC955	WR313
Well Name	AC818#1	GC955#1	WR313#1
Water Depth (m)	2744	2026	1917
Base of gas hydrate stability (m)	3197	2499	2758
Seafloor to base of gas hydrate stability (m)	453	473	841
Thermal gradient (mK/m)	~44	~32	~19
Target Facies sampled at the well	Volcani-clastic Oligocene sand	Pleistocene levee sands	Sheet sands within a minibasin

USGS

JIP drilling platform 2008

Planned LWD drilling at 3 sites in 2008

Coring in 2009

USGS

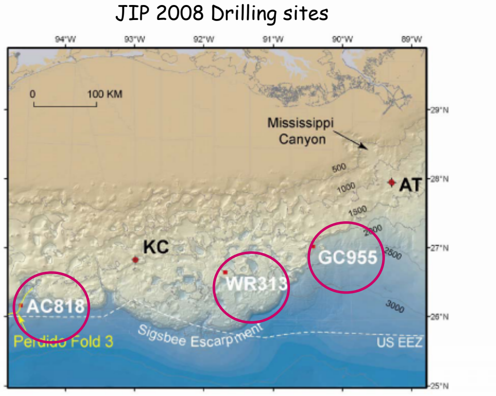
Arctic

- Drowned permafrost - climate change
- Offshore hydrate - hazards, resource
- North Slope AK - resource

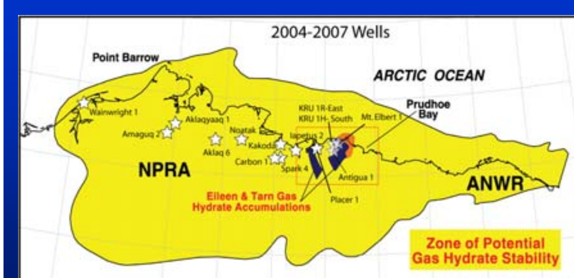
- (see posters)

USGS

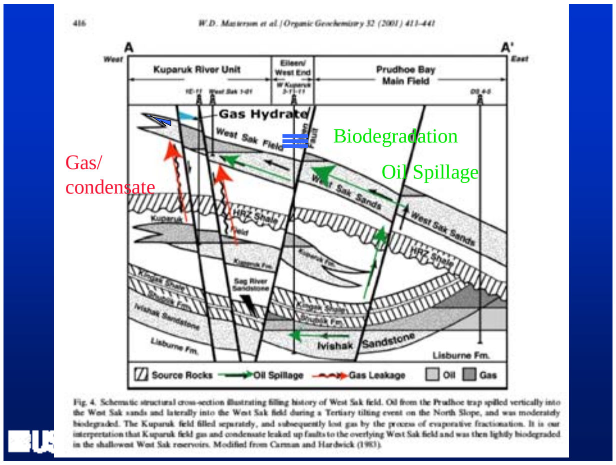
JIP 2008 Drilling sites



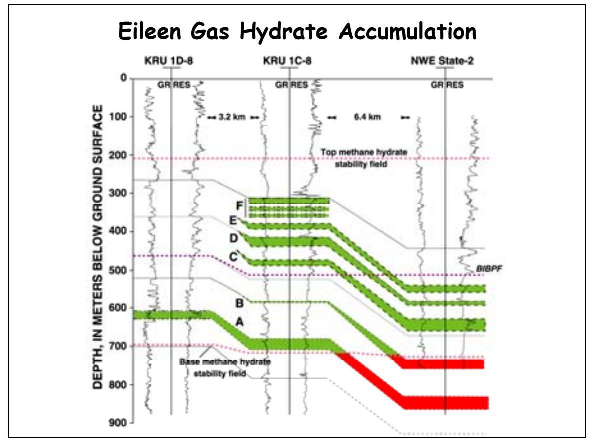
USGS



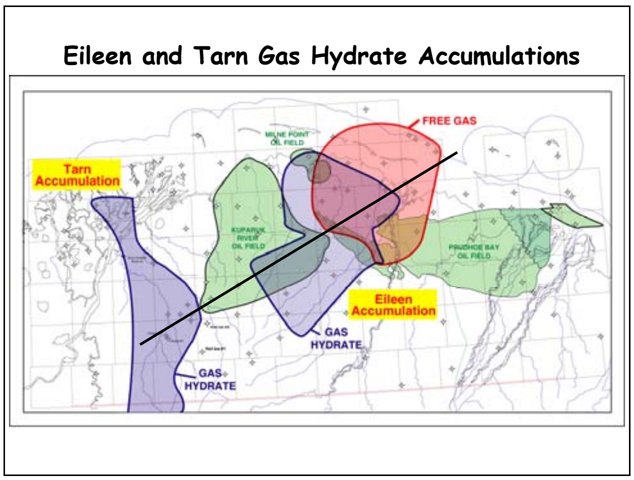
USGS



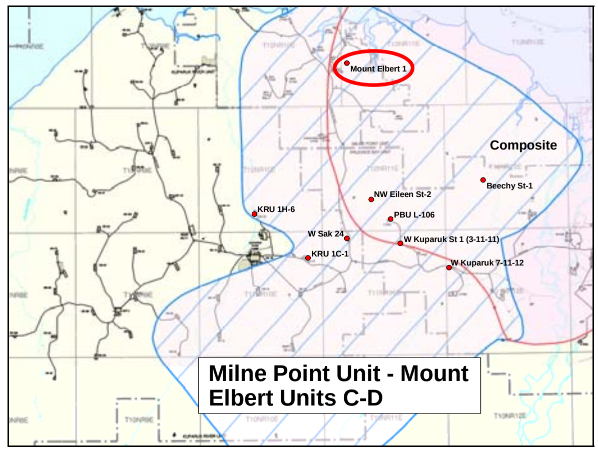
416
W.D. Masterson et al. / Organic Geochemistry 32 (2001) 411-441
A
A'
West
East
Kuparuk River Unit
Eileen/ West End
Prudhoe Bay Main Field
Gas Hydrate
Biodegradation
Oil Spillage
Gas/ condensate
West Sak Field
West Sak Sands
HRZ Shale
Sag River Sandstone
Ivishak Sandstone
Lisburne Fm.
Source Rocks
Oil Spillage
Gas Leakage
Oil
Gas
Fig. 4. Schematic structural cross-section illustrating filling history of West Sak field. Oil from the Prudhoe trap spilled vertically into the West Sak sands and laterally into the West Sak field during a Tertiary tilting event on the North Slope, and was moderately biodegraded. The Kuparuk field filled separately, and subsequently lost gas by the process of evaporative fractionation. It is our interpretation that Kuparuk field gas and condensate leaked up faults to the overlying West Sak field and was then lightly biodegraded in the shallowest West Sak reservoirs. Modified from Carman and Hardwick (1983).



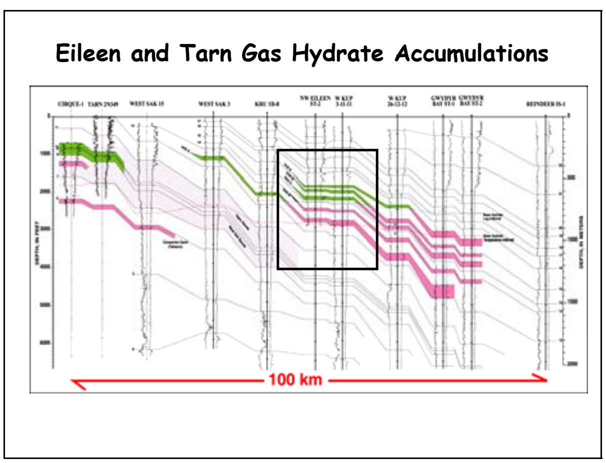
Eileen Gas Hydrate Accumulation
KRU 1D-8
KRU 1C-8
NWE State-2
GR RES
3.2 km
6.4 km
Top methane hydrate stability field
Base methane hydrate stability field
BIBPF
F
E
D
C
B
A
DEPTH, IN METERS BELOW GROUND SURFACE
0
100
200
300
400
500
600
700
800
900



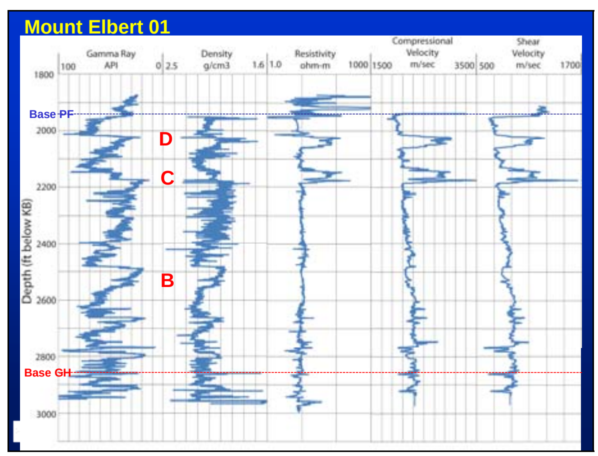
Eileen and Tarn Gas Hydrate Accumulations
FREE GAS
MILNE POINT OIL FIELD
Tarn Accumulation
KUPARUK RIVER OIL FIELD
PRUDHOE BAY OIL FIELD
Eileen Accumulation
GAS HYDRATE
GAS HYDRATE



Mount Elbert 1
Composite
Beechy St-1
NW Eileen St-2
KRU 1H-6
PBU L-106
W Sak 24
W Kuparuk St 1 (3-11-11)
KRU 1C-1
W Kuparuk 7-11-12
Milne Point Unit - Mount Elbert Units C-D



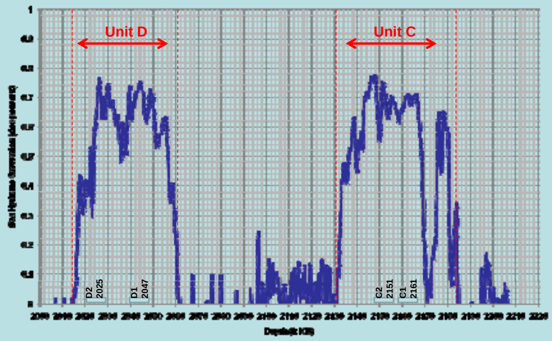
Eileen and Tarn Gas Hydrate Accumulations
100 km



Mount Elbert 01
Gamma Ray API
Density g/cm3
Resistivity ohm-m
Compressional Velocity m/sec
Shear Velocity m/sec
Base PF
D
C
B
Base GH
Depth (ft below KB)
1800
2000
2200
2400
2600
2800
3000

Mount Elbert 01 Gas Hydrate Units

NMR-DEN Derived Gas Hydrate Saturations



Gas Source

- Gas is mainly methane
- Very little CO_2, C_2
- Nitrogen up to 7%
- Narrow isotopic range of methane -43 to -50 ppt
- Average isotopic range -48 ppt
- Characteristic of biodegraded oil gas (-45 to -55 ppt)

Mount Elbert Unit C

–2132-2184 ft RKB, 52 ft thick
–Upper shale contact, lower water contact
–Gas Hydrate Saturation 65%
–Porosity 35%
–Permeability (intrinsic) 1,000 mD (NMR log)
–Reservoir Temp from MPU D-2: 3.3-3.9°C
–Hydrostatic pressure gradient (9792 Pa/m)
–Pore water salinities 5 ppt.

Eileen production models

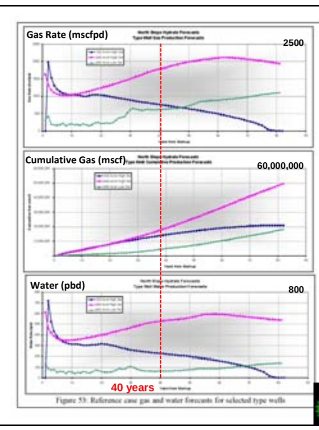
Developed by partners
LBNL
ANA
BP-Alaska

Mount Elbert Unit D

–2014-2061 ft RKB, 47 ft thick
–Shale bounded reservoir (top and bottom)
–Gas Hydrate Saturation 65%
–Porosity 40%
–Permeability (intrinsic) 1,000 mD (NMR log)
–Reservoir Temp from MPU D-2: 2.3-2.6°C
–Hydrostatic pressure gradient (9792 Pa/m)
–Pore water salinities 5 ppt.

Eileen Gas Hydrate Development Model

Upside Hydrate Well
-Gas Rate (mscfpd)
-Cumulative Gas (mscf)
-Water (bpd)



Next steps

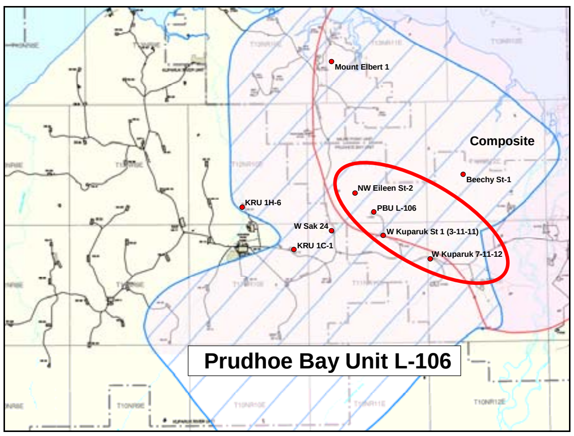
- Drilling of gas hydrate production test well early 2010
- Long term production testing by both thermal stimulation and depressurization
- **Long term production rate calculations are critical to evaluating field economics**

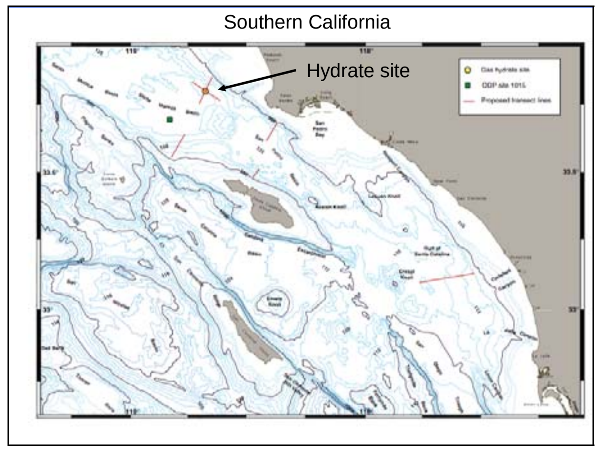
USGS

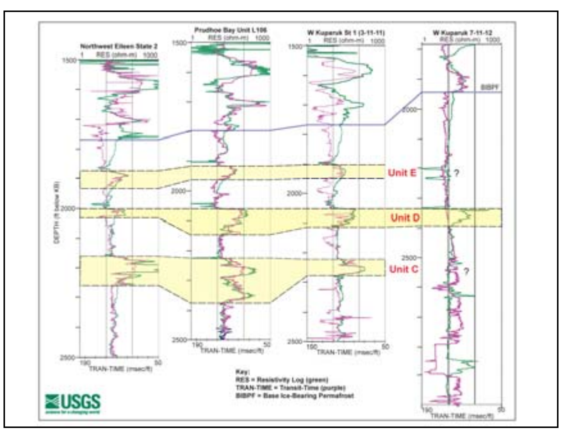
Southern California

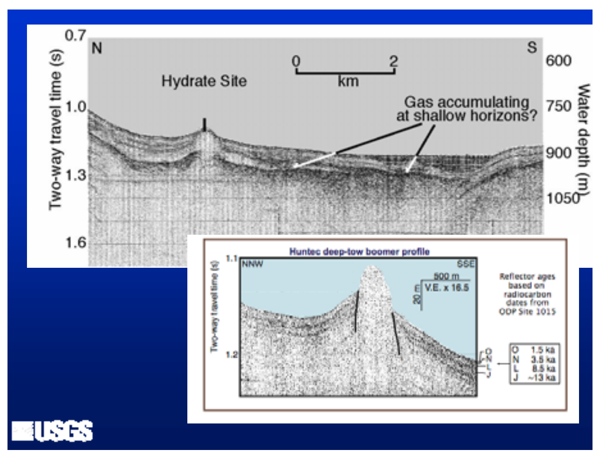
- Unexpected hydrate discovery in 2003
- Microbial gas
- Mapping and ROV sampling in 2005
- Extensive basin sands are a favorable target

USGS









Takk

USGS

Prudhoe Bay Unit L-106

–Two shale bounded hydrate layers:
(1) 2226-2288 ft, (2) 2318-2374 ft
–Gas Hydrate Saturation 75%
–Porosity 40%
–Permeability (intrinsic) 1,000 mD (NMR log)
–Reservoir Temp from MPU D-2: 5.0-6.5°C
–Hydrostatic pressure gradient (9792 Pa/m)
–Pore water salinities 5 ppt

4. Methane hydrate resources in Japan. Koji Yamamoto, Japan Oil, Gas, and Metals National Corporation

May 29, 2008

Impacts of the second on-shore methane hydrate production test results on the Japanese resource development

Research Consortium for Methane Hydrate Resources in Japan

Methane hydrate (hereinafter "MH") is an ice like solid substance that consists of cages formed with water molecules and methane (the main component of utility gas) molecules trapped in each cage. The vast majority of the volume of the substance has been found in marine sediments below the seabed in deep waters around Japan and other countries, and below permafrost layers in arctic regions like northern Canada and Alaska, as a mixture with sand grains. This material is an unconventional energy resource and is anticipated as a future form of alternative energy to conventional oil and natural gas. Due to its solid form, gas production from MH requires techniques to dissociate the substance to methane gas and water in a geological formation, and extract the gas through a borehole.

Since MH is stable under a high pressure and low temperature condition, the dissociation can be achieved by *temperature increase* (thermal stimulation) or *pressure decrease* (depressurization).

In 2002, seven organizations from five countries[1] joined a collaborative investigation program of methane hydrate in the same site as used again this year and conducted the first gas production test. In this original test, thermal stimulation by hot water circulation was tried and lead to the world's first intentional gas production from MH deposits. During the 123.7 hour operation term, 470m^3 gas was extracted from the formation. Although the success of the test proved that MH can be a gas reserve, the difficulty of the heat transport from a well to the formation limited the productivity of the thermal stimulation technique. Also the continuous injection of heat to the formation decreases the energy efficiency. More specifically, there can be many technical challenges of heat generation and transportation in deep water conditions.

On the other hand, the depressurization technique has advantages of operation and energy efficiency. The pressure decrease can be achieved by a simple operation of dropping the fluid level in wellbore by pumping water. However, the formation response to the high degree of depressurization was unknown in 2002 and many scientists were skeptical of the applicability of the technique. Nevertheless, in 2002 scientists attempted small scale pressure drawdown tests using wireline pressure logging tools in MH formations. The results of the test suggested the applicability of the simple depressurization technique for gas production. The subsequent series of laboratory and numerical works done by National Institute of Advanced Industrial Science and Technology (AIST) as a part of the MH21 (Research Consortium for Methane Hydrate Resources in Japan) study proved the applicability quantitatively.

As a result of the accumulated knowledge and experience, and with the expectation of the future application to the Japanese domestic resources, Japan Oil, Gas and Metals National Corporation (JOGMEC) and Natural Resources Canada (NRCan) signed an agreement to carry out a second production test at the site for the field scale verification of the depressurization technique.

Operation overview

The test site is located 130 km's north of Inuvik, in the Mackenzie Delta, and accessible

[1] Japan National Oil Corporation (JNOC, former JOGMEC), Japan, Geological Survey of Canada (GSC), Canada, GeoForschungsZentrum Potsdam (GFZ), the Department of Energy (DOE) and United State Geological Survey (USGS), US, the India Ministry of Petroleum and Natural Gas (MOPNG)-Gas Authority of India (GAIL), India, and the BP-Chevron Texaco Mackenzie Delta Joint Venture.

only in the winter season after ice road (a road on frozen river or ocean) construction is completed. All of the field activities should be terminated before the close of the ice roads. Due to the narrow seasonal operation window, the field work was divided into two winters (January-April 2007 and January-April 2008).

JOGMEC and NRCan funded the program and lead the research and development studies. Aurora College/Aurora Research Institute acted as the operator for the field program with support from Inuvialuit Oilfield Services who were the project managers.

Because the site is located in the very sensitive and weak northern environment, and various precious natural species live around the site, the project was required to maximize environment protection measures to assure that there was no impact on the wildlife and delicate arctic ecosystem. The test was conducted under the strict environmental regulations of Canadian authorities and with the consent local communities.

WINTER 2007: OPERATIONS

A well drilled for the 1998 research program (Mallik 2L-38) was reused for the production test for reducing drilling waste volumes. In the first winter, the well was modified for the production test, after geophysical data acquisition by state-of–the-art logging tools and deployment of downhole monitoring devices.

Severe cold (temperatures often reaches -40 degree C) lead to delay of the operation, but the test operation could start on the 2nd of April (local time) after the perforation (operation to make holes in the steel casing by gun powder) in a 12m interval at 1100m in depth was done and a set of a downhole pump systems to decrease the water level were installed.

Sand production (flow-in of formation sand to the borehole with fluid) prevented the continuous pumping, and the operation was terminated 60 hours after the start of the pumping. However, during the most successful 12.5 hours duration, at least 830m^3 of the gas was produced and accumulated in the borehole. This attempt was the world's first gas production by the depressurization of natural MH in geological formation, and the volume of 830m^3 exceeded the production volume of five-day-operation of 2002. We evaluated that the test result verified the effectiveness of the depressurization method even for such a short duration, but left technical challenges.

WINTER 2008: OPERATIONS

The goal of the winter 2008 field activities was to undertake longer term gas hydrate production testing with countermeasures to the problems of 2007.

After the ice road and site construction, and preparatory operations on the well, a modified pumping system was run into the hole with sand control devices. The pump operation started in the afternoon of March 10 and continued until the preset termination time of the test, noon of March 16.

Preliminary results

We can confirm that sustained gas flows ranging from 2000-4000 m^3/day were maintained throughout the course of the 6 day (139 hours) test. Cumulative gas production volume was approximately 13,000m^3. Detailed analysis will be made later, but we are sure that the result proves our hypothesis that the depressurization method is the correct approach.

During the test, a lot of data and samples, such as produced gas and water, their rate and volume, and downhole and surface pressure and temperatures were obtained. The analyses of the data and samples will help understanding MH dissociation behavior in formations, and contribute to the development of more sophisticated production techniques.

Within the MH21 research program, AIST is developing a reservoir simulation model called MH21-HYDRES. The predicted gas rate by the MH21-HYDRES is fairly matched with the observed value for the stable production terms. By analyzing the data of the production test, we expect improvement in the modeling.

Impacts on the Japanese MH research program

Japanese and Canadian research teams will analyze the data and publish scientific and

technical papers internationally.

According to the previous exploration results, original gas resources in place in the Eastern Nankai Trough area off the Pacific coast of Shizuoka through to Wakayama prefectures in the gas hydrate form is approximately 1.1 billion cubic meters (equivalent to 14 years of Japanese natural gas demand), and half of these areas form highly concentrated zones that are potentially high prospects of resources for development.

Development of effective production techniques is the key to change the naturally occurring gas hydrate to a valuable energy resource. The success of the production test in northern Canada is a great step forward.

A simulation result of MH21-HYDRES applied to one concentrated zone of the Eastern Nankai Trough reveals that the potential gas production rate from a single wellbore by the depressurization method can exceed 50,000m^3/day. The difference from the on shore production test result is caused by the extent of production interval, temperature and pressure conditions, geological and petro-physical conditions.

However, many technical issues remain for the application of depressurization techniques in marine sediments beneath deep water. Such technical challenges should be solved and verified through future production tests.

The future MH development should be environmentally friendly. Our experience in the delicate northern environment left many lessons. In the MH21 program, the Engineering Advancement Association (ENAA) takes part in the basic research on environmental protection and assessment.

Integrated studies of the exploration of the Eastern Nankai Trough and other areas, procuring techniques, and environmental impact studies are important for the future resource development.

The MH21 will provide the economics study on the concentrated zones of the Eastern Nankai Trough area with modeling studies later this year.

JOGMEC

National Institute of Advanced Industrial Science and Technology AIST

MHL AIST

MH21 Research Consortium

Research Consortium for Methane Hydrate Resources in Japan

Aurora College Your Career Starts Here

Natural Resources Canada Ressources naturelles Canada

B. Breakout Sessions

1. Characterisation and quantification of arctic hydrates

Session Chair: Thomas Lorenson

Suggested Topics:

What is the present status on arctic hydrates?

How well are the resorces quantified?

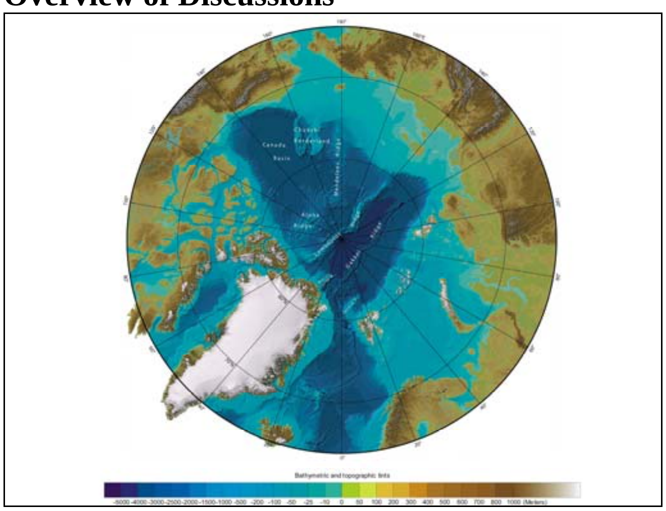
State of the art in measurements, from seismics to alternative and supplementary techniques. New approaches under development?

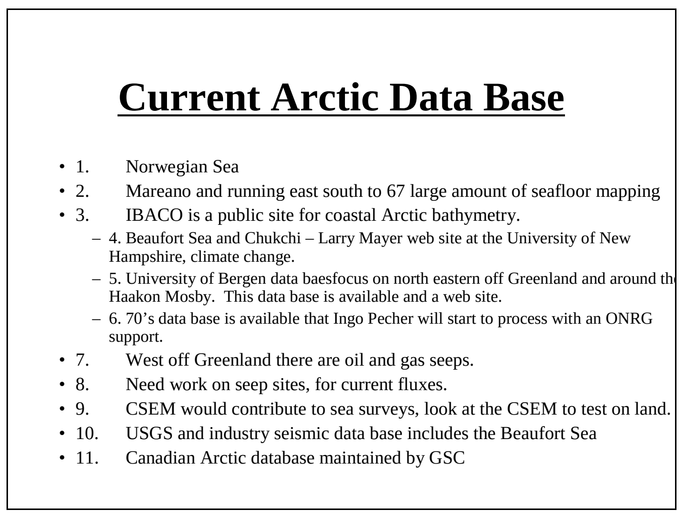
Core sampling techniques and implications for interpretations of results.

Differences in characteristics of reservoir topography, geology, thermodynamic conditions and trapping mechanism?

Implications for exploitation strategies?

Overview of Discussions



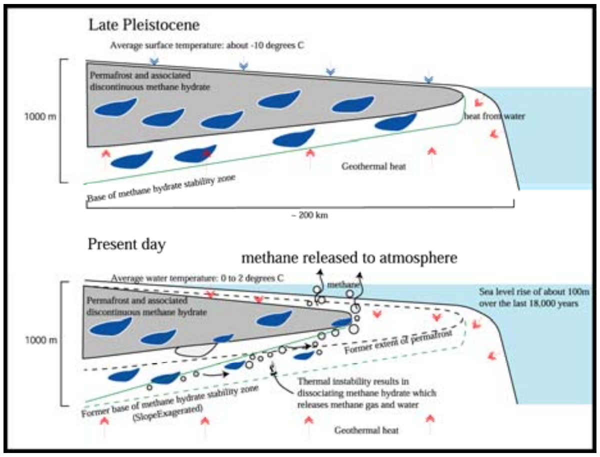


Permafrost Hydrates

- Known locations for permafrost regions that hydrates are being studied include:
  - 1. Mallik Wells
  - 2. Arctic slope to Wainwright Alaska
  - 3. May be Russian effort in Siberia that is similar to Prudhoe Bay.
  - 4. Messiaka gas field, Russia
  - 5. Other sites are marked on the chart.

Topics for climate change

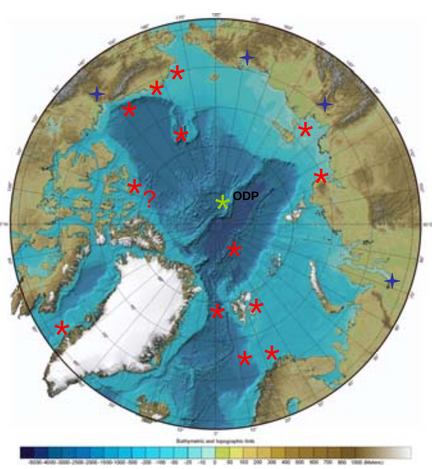
- There is a strong need to review currently available data. Topics for review include:
  - 1. Lake permafrost methane flux
  - 2. Look at freshwater and ice influence on ocean/atmosphere fluxes
  - 3. Literature shows relative methane flux from tundra and shallow coastal waters.
  - 4. Beaufort Shelf, Harrison Bay, 1977 data set will be examined for high velocity refractions.

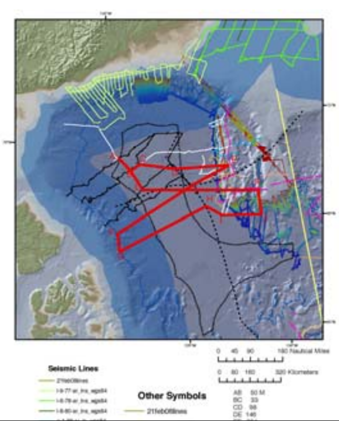


Law of the sea surveys

It was discussed that stated available data for focus on offshore hydrate beds and planning offshore hydrate exploration could be coupled with the Law of the Sea data gathering.

- Could contribute to the available seismic data, strong Canada-US effort, long seismics will be run with a short streamer and short bouys for velocity sound data.
- Seismics while breaking ice, difficult logistics in the program.





New Seismic and other techniques applied to surveys

- There was a quick conversation on approaches that are needed to be included in the field surveys and monitoring plans.
  - 1. Offshore approaches were not discussed during this session.
  - 2. On the North Slope there is some good 3-D methods that could be applied to nearshore and offshore surveys.
  - 3. New technology has not been applied to the Mackenzie Delta or off Russia.
  - 4. We need to consider application and new developments in CSEM.
  - 5. New sensor applications could be used for field monitoring.
  - 6. Remote sensors and satellite imaging could also be developed and tested.
  - 7. There is concern about setting long term monitoring platforms through ice seasons.

Other notes

- Tom Weingart is a good POC for future work conversations.
- Haflidi Haflidason, University of Bergen, is a good contact for work off the Norwegian side of the Arctic.
- Charts are available at www.mareano.no/kart/viewer.php

Core sampling techniques

Developing and application of new coring techniques was discussed. Issues addressed included:

- Need drill ship availability
- 5-6 m max experience with vibracoring, results from very compacted sediments. Also the sediments partially frozen, the piston coring may not work and vibracoring is needed.
- mini drill systems may be available.
- mebo coring/drill system (hydrolic) could be applied 50 meter cores can be obtained.
- Consider working in spring on a sea ice platform. This can fix the position. Look at winter work on the ice, roller guns.

Discussion sessions resulted in a statement that there is a strong need to review current Arctic research and monitoring programs and research publications. Tina Treude agreed to provide a summary of workshop participant's contributions to this information gathering. The following is information provided by the workshop attendees.

Arctic Related Web Sites

Alaska Lake Ice and Snow Observatory Network (ALISON) - http://www.gi.alaska.edu/alison/)

Arctic Military Environmental – Cooperation
http://www.google.co.uk/search?hl=en&q=Arctic+Military+Environmental+Cooperation&btnG=Google+Search&meta=

Arctic System Science - http://www.gisp2.sr.unh.edu/GISP2/ARCCS.html

Bridging the Poles Workshop - http://www.ldeo.columbia.edu/~mkt/PolarED_Web.htm

Barrow Arctic Research Consortium - http://www.arcticscience.org/

Danish Polar Center - http://www.dpc.dk/sw6492.asp

First International Symposium on the Arctic Research (ISAR-1), 2008 - http://www.jamstec.go.jp/iorgc/sympo/isar1/

Future Ocean Project, Kiel - http://www.uni-kiel.de/future-ocean/a2/index.shtml

Cold Regions Research and Engineering Laboratory (CRREL) in Hanover, NH. - http://www.crrel.usace.army.mil/projects/ and http://www.ehis.navy.mil/coe-london/factlist.asp?lab=CRREL

GANS Project - http://www.uib.no/people/nglbh/GANS/index.html

GLACIPET Project - http://www.ngu.no/glacipet/

MARENO Project - http://www.mareano.no/english/index.html

National Ice Center - http://www.natice.noaa.gov/

National Institute of Polar Research - http://www-arctic.nipr.ac.jp/e-index.html

National Snow and Ice Data Center - http://nsidc.org/data/index.html

Permafrost Institute in Siberia, Russia - http://www.sitc.ru/ync/ync_eng/ice.htm

Samylov Station in Siberia, Russia - http://www.awi.de/en/infrastructure/stations/samoylov_station/

Teachers and Researchers Exploring and Collaborating - http://www.arcus.org/TREC/index.php
Sustainability and Stewardship in Alaska - http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0331261

Science Journalists at Toolik Field Station
http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0425045

Toolik Field Station - http://www.uaf.edu/toolik/

University of New Hampshire, Arctic Research - http://www.ccrc.sr.unh.edu/~cpw/ArcticRes/ArcticRes.html

U.S. Army Permafrost Tunnel - http://www.crrel.usace.army.mil/permafrosttunnel/

USGC - http://pubs.usgs.gov/of/1995/of95-070/core/meta/report.html

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Hinkel et al. 2003. Spatial Extent, Age, and Carbon Stocks in Drained Thaw Lake Basins on the Barrow Peninsula, Alaska. Arctic, Antarctic and Alpine Research. 3:291-300.

Hinkel and Nelson. 2003. Spatial and temporal patterns of active layer thickness at Circumpolar Active Layer Monitoring (CALM) sites in northern Alaska, 1995-2000. J. Geophy. Res. NO. D2 8168, doi:10.1029/2001/ JD000927/

Schmidt et al. 2004. General circulation modeling of Holocene climate variability. Quat. Sci. Rev. 2167-2181.

Tripati et al. 2005. Eocene bipolar glaciation associated with global carbon cycle changes. Nature doi:10.1038.

Arctic Ocean References

Bockheim et al. 2003. Factors affecting the distribution of *Populus balsamifera* on the North Slope of Alaska, USA. Arctic, Antarctic and Alpine Research. 55:331-340.

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Shakhova et al. 2005. The distribution of methane on the Siberian Arctic shelves: Implications for the marine methane cycle. Geophys. Res. Let., VOL. 32, L09601, doi:10.1029/2005GL022751

Shakhova & Semiletov 2007. Methane release and coastal environment in the East Siberian Arctic shelf. Journal of Marine Systems 66 (2007) 227–243

Diverse References

http://www.uib.no/people/nglbh/GANS/Relevant_literature.html

http://www.crrel.usace.army.mil/library/technicalpublications.html

2. Exploitation strategies and technical challenges

Session Chair: Koji Yamamoto

Suggested Topics

Relative to exploitation strategies for marine hydrates - what are are the main differences and corresponding challenges related to arctic hydrates?

Flow assurance - including reservoir and pipeline infrastructure

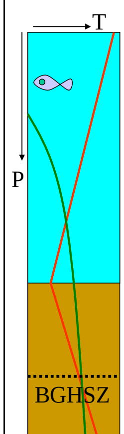
Overview of Discussions

Session E: Exploitation strategies and technical challenges

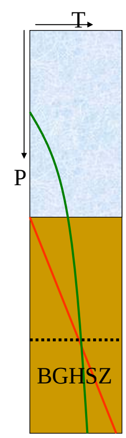
Rapporteur K. Yamamoto, JOGMEC

- Difference between Marine and Arctic Hydrate
  - Physical & geological conditions
  - Technology & Hazard
  - Economics
  - Environmental issues
  - Summary and common concerns

Technology/hazard

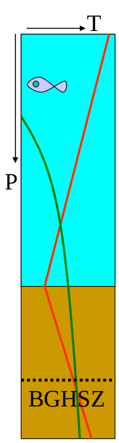


- Marine
  - More chance of simple depressurization
  - No cap rock (soft plastic sediment)
  - Bottom-hole separation and water flush at the sea floor
  - Gravel pack:OK

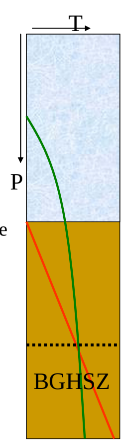


- Arctic
  - Low temperature/ pressure requires heat supply with depressurization
  - Thick hard cap rock (permafrost)
  - Flow assurance is more serious by low temperature
  - Few sand control options

Physical/geological Conditions

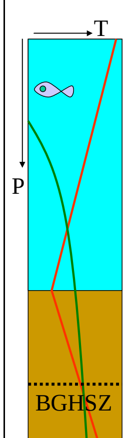


- Marine
  - T=4-15deg
    - Never sub zero
  - Muddy sediments with channel /turbidite sand
    - More vein and fracture-fill type hydrate with some pore-filling
    - Analogue: shale gas
  - Large horizontal continuity
    - Patterned well arrangement

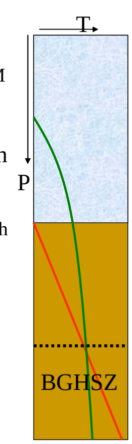


- Arctic
  - T=0-10degC
    - Sub-zero temperature in overburden
  - Sandy sediments
    - Pore-filling hydrate
  - Poor horizontal continuity
    - Hot spots

Economics

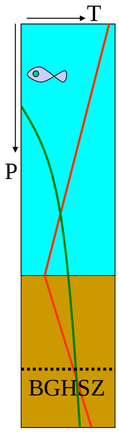


- Marine
  - Usually remote from market
    - Exception: GOM
  - Large scale projects are necessary by high CAPEX
    - Chance of small scale project with NGH, CNG transportation?
  - Analogue: shallow gas (hazard to asset below existing infrastructure)
  - .

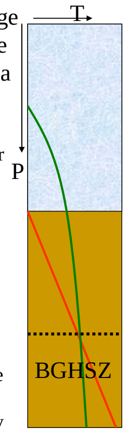


- Arctic
  - Local/internal demand
    - EOR of heavy oil
    - Local community and industry
  - A small scale project can be feasible if infrastructure is there

Environmental issues



- Marine
  - Small scale leakage is not a matter due to the buffer of sea water
    - Leaked gas dissolves to water soon
  - Large scale or catastrophic troubles are the concern
    - Catastrophic release
    - Tilt of the surface facility due to surface instability



- Arctic
  - Very, very sensitive and regulations are strict
    - Small leakage may kill the project
  - Little chance of subsidence due to the thick permafrost
    - Effect on PF
  - Monitoring
    - Excess pore pressure
    - Deformation

Summary and common concerns

- Various options for even a small scale production project, if
  - Demand is here ...
  - Infrastructure is here ...
- Environmentally sensitive, small scale leakage is not allowable
- Heat support is necessary with depressurization due to low temperature
- More serious flow assurance concerns than marine
- Regulation issues; Is a special low for gas hydrate necessary?
- Any new revolutional ideas for efficient production?

3. Theoretical modeling

Session Chair: Gerard Nihous

Suggested Topics:

What is state of the art on theoretical modelling relative to arctic hydrates?

Fundamental understanding of hydrate/rock interactions?

Phase transition dynamics for hydrate/ice and hydrate/fluid? What are the main rate limiting factors and what is the corresponding state of the art in modelling? Directions for future research?

What is state of the art on the reservoir modelling and corresponding limitations? Directions for future research?

Overview of Discussions

Breakout session F: Theoretical Modeling

- Identified 4 primary modeling areas of interest to methane hydrate production and science:
  - Rock physics
  - Flow (reservoir) simulations
  - Geomechanical models
  - Environmental models of the fate of released CH_4

Rock Physics

<u>State of the Art</u>

- Existing models (e.g., grain replacement models) appear to match data on sonic properties and strength well

<u>Areas of Future Focus</u>

- Complex substrates/matrices
- Adhesion of hydrate to different substrates

Flow Simulators

<u>State of the Art</u>

- Mature technology
- Current models are robust and versatile and can accurately predict reservoir dynamics

<u>Areas of Future Focus</u>

- Need to refine submodels of hydrate-rock interactions; e.g., wettability
- Current models may not be appropriate as-is for applications such as rapid depressurization
- Hydrate kinetics??—probably not relevant; models presume quasi-equilibrium

Environmental Models

<u>State of the Art</u>

- Arctic may be the region where hydrate outgassing could impact climate
- Limited effort to date on simulating the fate of outgassed methane
- Platforms exist (OGCMs, atmospheric transport/chemistry models) that could be adapted to consider methane sources from seafloor or permafrost

<u>Areas of Future Focus</u>

- Need to incorporate submodels of methane sources, CH_4 oxidation, and (for intense ocean leakage) bubble models into OGCMs—this is not trivial
- Can models developed to track CO_2 in the ocean be "tweaked" to accommodate CH_4 leakage scenarios?
- Modeling workshop?

Geomechanical Models

<u>State of the Art</u>

- Focus on well bore stability and/or submarine slope stability
- Common thread with rock physics and reservoir models is issue of hydrate-substrate interaction

<u>Areas of Future Focus</u>

- As with the previous models, data is needed to better understand (and simulate) the physics of adhesion/wettability at the hydrate-substrate interface

Other Points

- More intensive interactions between modelers and experimentalists need to be encouraged
- Experiments to obtain fundamental data on hydrate-substrate interfacial phenomena not trivial but should be pursued
- May be worthwhile to conduct molecular simulations to determine absolute values of important thermodynamic properties
- Models of hydrate destabilization and formation kinetics must shift away from past "difference" approaches

C. Panel Discussion: Arctic Hydrates - Future challenges and corresponding strategies for extended international collaboration

Panel

James Howard, ConocoPhillips
Rik Drenth, Shell
Ingo Pecher Herriot-Watt University
Koji Yamamoto JOGMEC
Tom Lorenson USGS Menlo Park

Suggested Topics

On the basis of the breakout sessions - what is current status and what are the main challenges that need to be addressed before commercial exploitation from arctic hydrates can be a reality?

Are there any incitements for international collaboration beyound Mallik II and other ongoing projects? And if so what would be the motivating factors for releasing corresponding funding from the different worldwide groups that would like to collaborate?

Is it possible to pinpoint keywords of a strategy document that can be used as a basis for funding applications?

Opening remarks

James Howard–

Production Testing, Mallik ongoing testing has started, Alaska is being planned, Russia is slow

1. Challenges for commercialization
2. Technical issues deal with reservoir modeling capabilities, environmental

Question
How does the industry move past models to testing?

Answer
There is not a reservoir simulator model, except for Stars. Drilling will be staged with single well tests with simple analysis tools. Set for 2010-2011. This will include depressurization with chemicals and CO_2. Need an advanced scale simulator that will take time. Modeling needs to be up-scaled. Ten year to development of full scale field project.

Question addressed to the audience from James Howard -How much hydrate chemistry is need for prediction of well success?

Panel Comments
Yamamoto discussed the dissociation zone and need to explain this region. There is a need for development understanding and modeling of the dissociation zone. We need to address the parameters that limit the dissociation. This is likely a function of heat transport limitation.

Drenth simulation model is more well developed and started with well format design and then included the physical environmental parameters. Challenges will be modeling mud rich drilling, models do not address this. This could take longer than 10 years.

Comment
Warren Wood – What is needed for development, is it more field tests.

Drenth responds – We need more theoretical models but also need more field tests.

Howard responds – Industry does not have the expertise and man power for the projects. There is a need to leverage academic institutes into these programs.

Kvamme states - There is a need for sharing international funds for program development.   Requests development of collaboration on field tests, experiments for mining.

Pecher states - Seismology has made strong progress in applying this approach to hydrate surveys. There is a need for calibration of the seismics. Archies law approach with resistivity is too simple and we need to combine lab and field work to assist with data development. Furthermore we need a strong development pressure cores and conducting physical and chemical analysis of pressure cores.

Comment
There is a need for hydrate modeling in sand.

Kvamme states - There is development of pressure cores and testing. This was confirmed with the audience responding.

Comment
Treude – There is a need for more pressure core research. Vision of large chips of hydrates in the core that need more understanding. Need for subsamples under pressures.

Audience response - Need longer cores through transfer device and keep them under pressure. Geotech system provides core sub sampling under pressure.

Kvamme - Agrees with the need of subsample coring.

Comment
Southampton has developed a lot of the subsampling. John Parks has developed microbiologist sampling chamber.

Comment
Tom Lorenson - Evidence for gas hydrate dissociation was first addressed with CH_4 concentration in the water column. There was evidence for methane seepage. First estimate for ocean to atmosphere, was 1/200 to 1/300 of the total input. There is a strong need for addressing methane input to the atmosphere, methane dissociation.

Comment
Hamdan – Well applications were discussed through the workshop, what about risk assessment for environmental impact.

Howard responds that this will be monitored because of worry for damage to the program, this will include geomechanical analysis. Drilling hazard will be included. A committee addresses this issue. However there is not a thorough environmental impact addressed.

Drenth states that there is environmental concern that Shell has addressed theoretical models but this has not been tested.

Howard states that environmental monitoring for coal bed can be applied to methane drilling monitoring. Also nothing is currently being planned.

It was stated that this is a difficult topic to get into the public eye.

General Final Statements:
Kvamme brought up that we need Russian included. FMU Akida, in Germany will be contacted in the government.

Langhorne gave an overview of development of an arctic program focusing on climate change, not hydrates energy. Langhorn says that Navy should stay out of this and we can put this through IIASA.

Simulations not accomplished but the experimentalists need to know what the modelers need. That whole format goes with the field scientists also. This is a necessity. Theory, field and experiments need to model.

Treude offered to search website for information on the Arctic Ocean and climate change. This information is included in the Characterization and Quantification of Arctic Hydrates session (above).

VI. Posters Presented at the Workshop

1. Geochemical and geophysical data integration for preliminary hydrate surveys across the Porangahau Ridge on the Hikurangi Margin, New Zealand. (R. Coffin, NRL: USA)

2. Monitoring of temporally and spatially transient bubble release and the special extrapolates of methane fluxes: use of hydro acoustic methods in the Black sea … and what New Zealand sheep have to d with it. (J. Greinert, Renard Center of Marine Geology: Belgium)

3. Thermal modeling of marine hydrate in changing environments. (A. Lemon, Univ. Leicester: UK)

4. Assessing concentration of methane hydrate in marine sediments. (P. Jackson, Univ. Leicester: UK)

5. Shallow sediment carbon cycling driven by deep methane vertical flux: Atwater Valley on the Texas-Louisiana shelf. (R. Coffin, NRL: USA)

6. Deformation of methane hydrate supported sand during its dissociation. (M. Hyodo, Univ. Yamaguchi: Japan)

7. Gas hydrate and associated free gas across the Alaskan Beaufort Sea outer continental margin. (P. Hart, USGS: USA)

8. Origin of hydrocarbon gases in gas hydrates from the Alaskan North Slope, USA. (Lorenson, USGS: USA)

9. Gas hydrates and seafloor warming: research within the future ocean project in Kiel, Germany. (T. Treude, IFM-GEOMAR: Germany)

10. Submarine gas hydrate exploration, exploitation and transport (SUGAR). (IMF-GEOMAR: Germany)

11. Sallow upper boundary of gas hydrate stability zone in the Okhotsk sea: Implications of dynamic of gas hydrates in the cold sea. (J.K. Jin, Korean Polar Res. Inst.: Korea)

12. Casing stability modeling in gas hydrate bearing sediments. (M. Salehabadi, Petronas Res. SDN. BHD. :Malaysia)

13. T. Fujii, JOGMEC : Japan

14. Gas hydrates on the Norway-Barents Sea-Svalbard margin (GANS). (H. Haflidason, Univ. Bergen: Norway)

15. Gas seepage from the Cascadian Arctic shelf and seeps of the Mackenzie river Delta, NWT, Canada. (T. Lorenson, USGS: USA)

16. Norwegian margin fluid escape structures – sedimentary environments and evolutions. (B.O. Hjelstuen, Univ. Bergen: Norway)

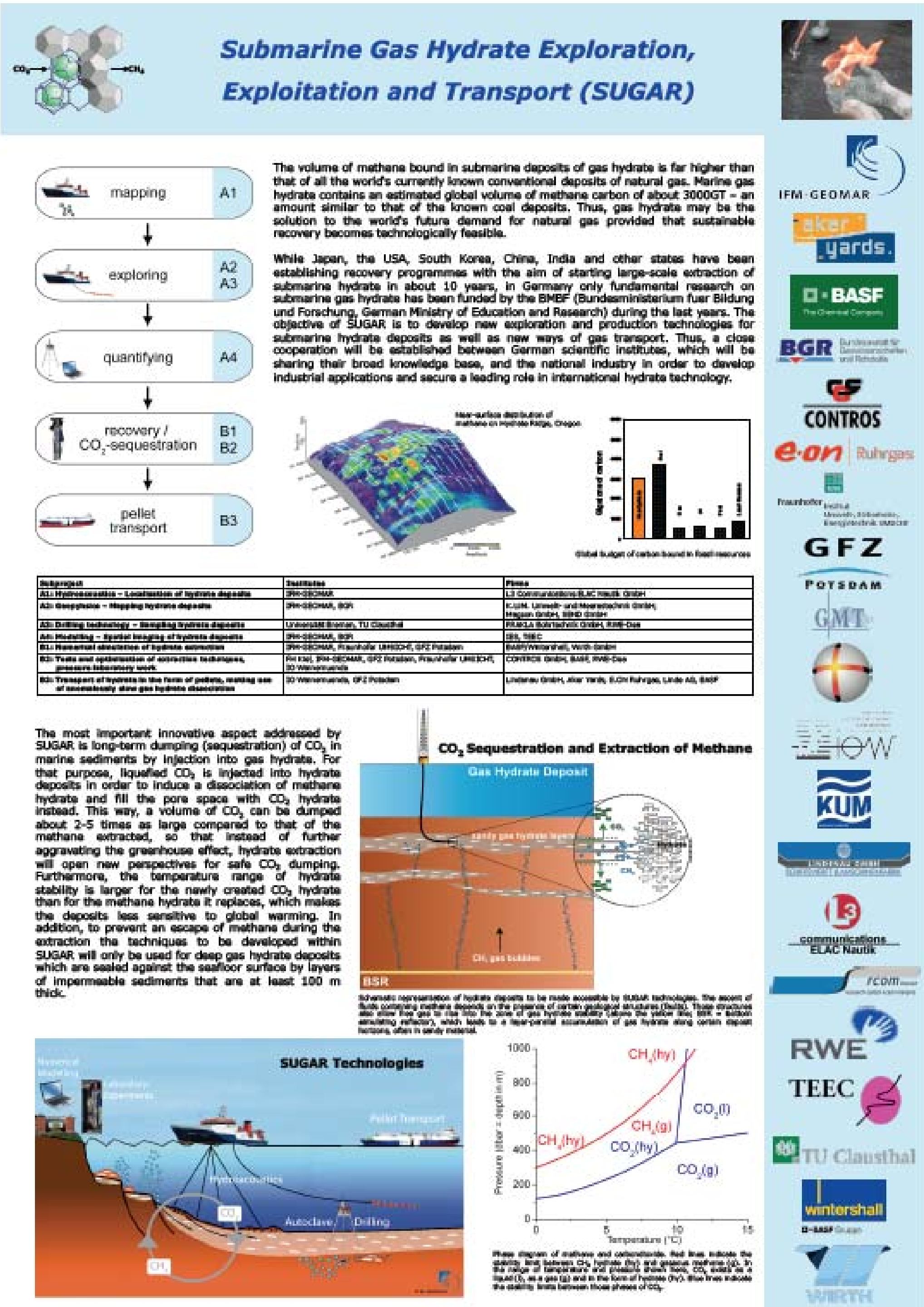
17. Geomicrobal characterization of gas seep sediments using a novel molecular biological method. (L. Hamdan, NRL: USA)

18. Well bore stability problem for methane hydrate extraction. (S.L. Lee, Univ. Cambridge: UK)

19. Geomechanical study of methane hydrate soil: micromechanics. (J. Brugada, Univ. Cambridge: UK)

20. Clathrate hydrate crystals observed via transmission electron microscope. (T. Uchida, Hokkaido Univ.: Japan)

VII. Posters Published



Submarine Gas Hydrate Exploration, Exploitation and Transport (SUGAR)

mapping A1

exploring A2 A3

quantifying A4

recovery / CO_2-sequestration B1 B2

pellet transport B3

The volume of methane bound in submarine deposits of gas hydrate is far higher than that of all the world's currently known conventional deposits of natural gas. Marine gas hydrate contains an estimated global volume of methane carbon of about 3000GT – an amount similar to that of the known coal deposits. Thus, gas hydrate may be the solution to the world's future demand for natural gas provided that sustainable recovery becomes technologically feasible.

While Japan, the USA, South Korea, China, India and other states have been establishing recovery programmes with the aim of starting large-scale extraction of submarine hydrate in about 10 years, in Germany only fundamental research on submarine gas hydrate has been funded by the BMBF (Bundesministerium fuer Bildung und Forschung, German Ministry of Education and Research) during the last years. The objective of SUGAR is to develop new exploration and production technologies for submarine hydrate deposits as well as new ways of gas transport. Thus, a close cooperation will be established between German scientific institutes, which will be sharing their broad knowledge base, and the national industry in order to develop industrial applications and secure a leading role in international hydrate technology.

Near-surface distribution of methane on Hydrate Ridge, Oregon

Global budget of carbon bound in fossil resources

Subproject	Institutes	Firms
A1: Hydroacoustics – Localisation of hydrate deposits	IFM-GEOMAR	L3 Communications ELAC Nautik GmbH
A2: Geophysics – Mapping hydrate deposits	IFM-GEOMAR, BGR	K.U.M. Umwelt- und Meerestechnik GmbH, Magson GmbH, SEND GmbH
A3: Drilling technology – Sampling hydrate deposits	Universität Bremen, TU Clausthal	PRAKLA Bohrtechnik GmbH, RWE-Dea
A4: Modelling – Spatial imaging of hydrate deposits	IFM-GEOMAR, BGR	IBS, TEEC
B1: Numerical simulation of hydrate extraction	IFM-GEOMAR, Fraunhofer UMSICHT, GFZ Potsdam	BASF/Wintershall, Wirth GmbH
B2: Tests and optimisation of extraction techniques, pressure laboratory work	FH Kiel, IFM-GEOMAR, GFZ Potsdam, Fraunhofer UMSICHT, IO Warnemuende	CONTROS GmbH, BASF, RWE-Dea
B3: Transport of hydrate in the form of pellets, making use of anomalously slow gas hydrate dissociation	IO Warnemuende, GFZ Potsdam	Lindenau GmbH, Aker Yards, E.ON Ruhrgas, Linde AG, BASF

The most important innovative aspect addressed by SUGAR is long-term dumping (sequestration) of CO_2 in marine sediments by injection into gas hydrate. For that purpose, liquefied CO_2 is injected into hydrate deposits in order to induce a dissociation of methane hydrate and fill the pore space with CO_2 hydrate instead. This way, a volume of CO_2 can be dumped about 2-5 times as large compared to that of the methane extracted, so that instead of further aggravating the greenhouse effect, hydrate extraction will open new perspectives for safe CO_2 dumping. Furthermore, the temperature range of hydrate stability is larger for the newly created CO_2 hydrate than for the methane hydrate it replaces, which makes the deposits less sensitive to global warming. In addition, to prevent an escape of methane during the extraction the techniques to be developed within SUGAR will only be used for deep gas hydrate deposits which are sealed against the seafloor surface by layers of impermeable sediments that are at least 100 m thick.

CO_2 Sequestration and Extraction of Methane

Gas Hydrate Deposit

sandy gas hydrate layers

CH_4 gas bubbles

BSR

Schematic representation of hydrate deposits to be made accessible by SUGAR technologies. The ascent of fluids containing methane depends on the presence of certain geological structures (faults). These structures also allow free gas to rise into the zone of gas hydrate stability (above the yellow line; BSR = bottom simulating reflector), which leads to a layer-parallel accumulation of gas hydrate along certain deposit horizons, often in sandy material.

SUGAR Technologies

Pellet Transport

Hydroacoustics

Autoclave

Drilling

CO_2

CH_4

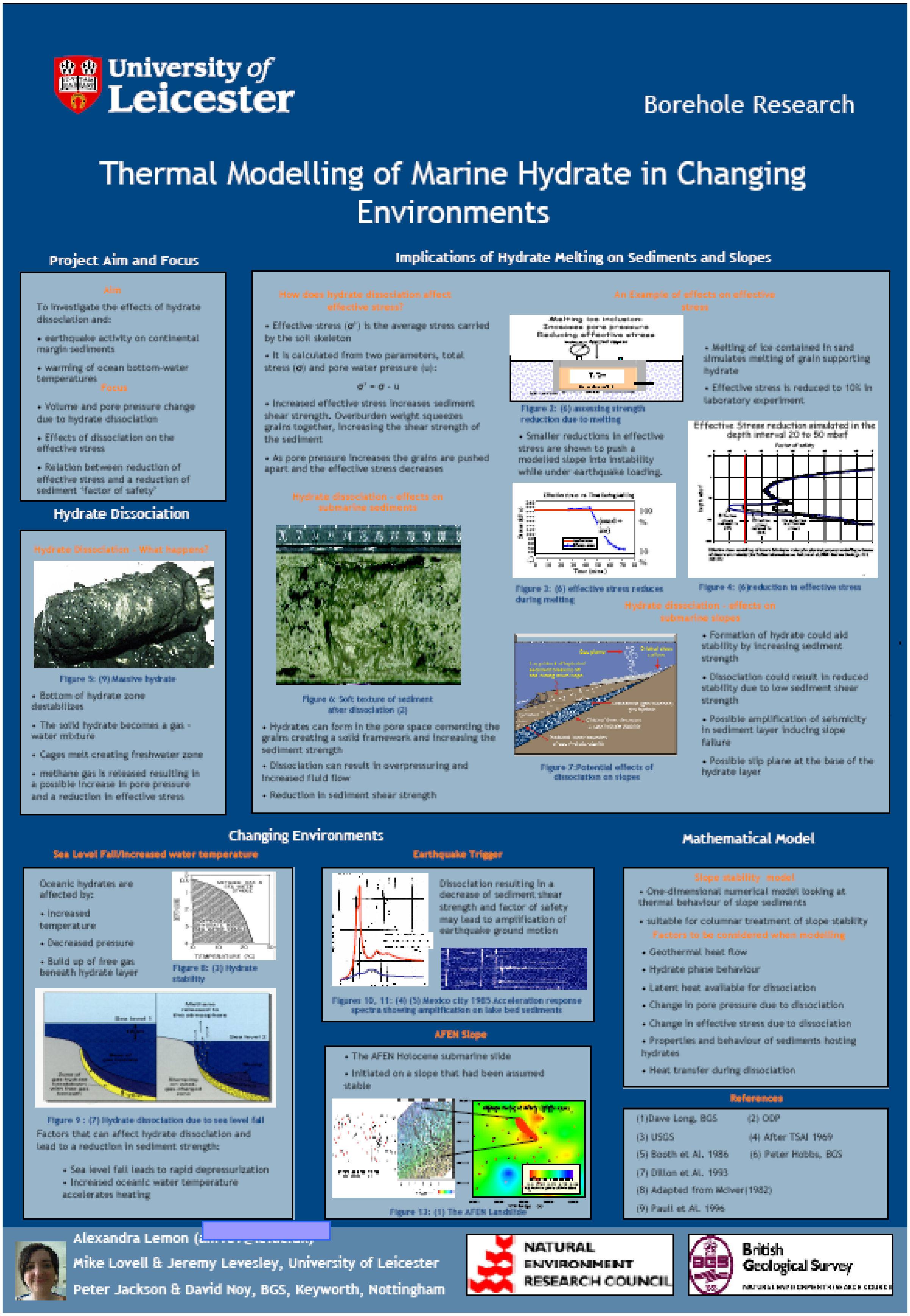
$CH_4(hy)$, $CH_4(g)$, $CO_2(l)$, $CO_2(hy)$, $CO_2(g)$

Pressure (dbar = depth in m)

Temperature (°C)

Phase diagram of methane and carbondioxide. Red lines indicate the stability limit between CH_4 hydrate (hy) and gaseous methane (g). In the range of temperature and pressure shown here, CO_2 exists as a liquid (l), as a gas (g) and in the form of hydrate (hy). Blue lines indicate the stability limits between those phases of CO_2.

IFM-GEOMAR, aker yards, BASF The Chemical Company, BGR, CONTROS, e·on Ruhrgas, Fraunhofer Institut Umwelt-, Sicherheits-, Energietechnik UMSICHT, GFZ Potsdam, GMT, IOW, KUM, Lindenau GmbH, L3 communications ELAC Nautik, RWE, TEEC, TU Clausthal, wintershall, WIRTH


University of Leicester
Borehole Research
Thermal Modelling of Marine Hydrate in Changing Environments
Project Aim and Focus
Aim
To investigate the effects of hydrate dissociation and:
• earthquake activity on continental margin sediments
• warming of ocean bottom-water temperatures
Focus
• Volume and pore pressure change due to hydrate dissociation
• Effects of dissociation on the effective stress
• Relation between reduction of effective stress and a reduction of sediment 'factor of safety'
Hydrate Dissociation
Hydrate Dissociation – What happens?
Figure 5: (9) Massive hydrate
• Bottom of hydrate zone destabilizes
• The solid hydrate becomes a gas - water mixture
• Cages melt creating freshwater zone
• methane gas is released resulting in a possible increase in pore pressure and a reduction in effective stress
Implications of Hydrate Melting on Sediments and Slopes
How does hydrate dissociation affect effective stress?
• Effective stress (σ') is the average stress carried by the soil skeleton
• It is calculated from two parameters, total stress (σ) and pore water pressure (u):
σ' = σ - u
• Increased effective stress increases sediment shear strength. Overburden weight squeezes grains together, increasing the shear strength of the sediment
• As pore pressure increases the grains are pushed apart and the effective stress decreases
Hydrate dissociation – effects on submarine sediments
Figure 6: Soft texture of sediment after dissociation (2)
• Hydrates can form in the pore space cementing the grains creating a solid framework and increasing the sediment strength
• Dissociation can result in overpressuring and increased fluid flow
• Reduction in sediment shear strength
An Example of effects on effective stress
Melting ice inclusion:
Increases pore pressure
Reducing effective stress
Figure 2: (6) assessing strength reduction due to melting
• Melting of ice contained in sand simulates melting of grain supporting hydrate
• Effective stress is reduced to 10% in laboratory experiment
• Smaller reductions in effective stress are shown to push a modelled slope into instability while under earthquake loading.
100 %
10 %
Time (mins)
Figure 3: (6) effective stress reduces during melting
Effective Stress reduction simulated in the depth interval 20 to 50 mbsf
Factor of safety
Figure 4: (6)reduction in effective stress
Hydrate dissociation – effects on submarine slopes
Gas plume
Figure 7:Potential effects of dissociation on slopes
• Formation of hydrate could aid stability by increasing sediment strength
• Dissociation could result in reduced stability due to low sediment shear strength
• Possible amplification of seismicity in sediment layer inducing slope failure
• Possible slip plane at the base of the hydrate layer
Changing Environments
Sea Level Fall/Increased water temperature
Oceanic hydrates are affected by:
• Increased temperature
• Decreased pressure
• Build up of free gas beneath hydrate layer
TEMPERATURE (°C)
Figure 8: (3) Hydrate stability
Sea level 1
Sea level 2
Figure 9 : (7) Hydrate dissociation due to sea level fall
Factors that can affect hydrate dissociation and lead to a reduction in sediment strength:
• Sea level fall leads to rapid depressurization
• Increased oceanic water temperature accelerates heating
Earthquake Trigger
Dissociation resulting in a decrease of sediment shear strength and factor of safety may lead to amplification of earthquake ground motion
Figures 10, 11: (4) (5) Mexico city 1985 Acceleration response spectra showing amplification on lake bed sediments
AFEN Slope
• The AFEN Holocene submarine slide
• Initiated on a slope that had been assumed stable
Figure 13: (1) The AFEN Landslide
Mathematical Model
Slope stability model
• One-dimensional numerical model looking at thermal behaviour of slope sediments
• suitable for columnar treatment of slope stability
Factors to be considered when modelling
• Geothermal heat flow
• Hydrate phase behaviour
• Latent heat available for dissociation
• Change in pore pressure due to dissociation
• Change in effective stress due to dissociation
• Properties and behaviour of sediments hosting hydrates
• Heat transfer during dissociation
References
(1)Dave Long, BGS
(2) ODP
(3) USGS
(4) After TSAI 1969
(5) Booth et Al. 1986
(6) Peter Hobbs, BGS
(7) Dillon et Al. 1993
(8) Adapted from McIver(1982)
(9) Paull et Al. 1996
Alexandra Lemon (
Mike Lovell & Jeremy Levesley, University of Leicester
Peter Jackson & David Noy, BGS, Keyworth, Nottingham
NATURAL ENVIRONMENT RESEARCH COUNCIL
British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

UNIVERSITY OF CAMBRIDGE

CONACYT

Geomechanical Study of Methane Hydrate Soil: Micromechanics

J. Brugada[1], K. Soga[2]

This research is funded by the National Council of Science and Technology of Mexico (CONACYT)

① Introduction

The study of geomechanical behaviour of methane hydrate-bearing soils has followed a continuum mechanics approach. Klar & Soga (2005) have formulated a coupled flow-deformation model in which the soil structure is assumed to consist of two separate continua (soil and hydrate), each of which has its own elasto-plastic behaviour. Different hypotheses have been formulated for methane hydrate formation at particle scale. However, there is little understating on how the microscale processes related to hydrate formation affect the geomechanical behaviour of sediments. The aim of this research is to study the effect of the *different methane hydrate growth patterns on the geomechanical behaviour of hydrate-bearing* soils. A micro-mechanical study is proposed using the Discrete Element Method (DEM), which will consist of simulation of triaxial tests.

② Engineering Properties of Methane Hydrate Soil

✓ The strength depends on S_{MH} (Fig. 1).

✓ Presence of gas hydrate increases the shear resistance (Fig. 1) and enhances dilation (ψ) similar to cemented sand (Fig. 3).

✓ The average friction angles (ϕ') for natural and man-made samples are 35° and 31° respectively, independent of S_{MH}. Cohesion tends to increase with S_{MH} (Fig. 2). This leads to the hypothesis that gas hydrate *only contributes* to *the increase in cohesion* and has *no effect on friction angle.*

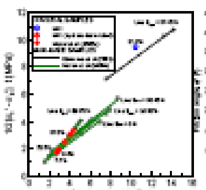


Fig. 1: Yield criteria of natural and man-made gas hydrate sand samples (Soga et al, 2006)

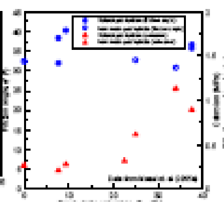


Fig. 2: Relationship between friction angle and cohesion with gas hydrate saturation

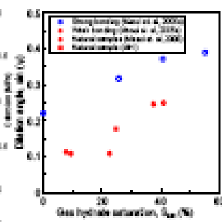
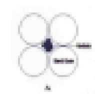


Fig. 3: Effect of gas hydrate saturation on dilation angle

③ Models of Methane Hydrate Growth

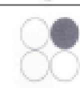
Model A: Pore filling

- Hydrate is part of the pore fluid
- Methane hydrate affects the bulk modulus of the pore fluid and the bulk density of the sediment



Model B: Frame-building

- Hydrate is part of the frame: supporting matrix
- Sediment porosity reduces with hydrate saturation

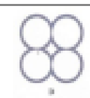


Model C: Cementation

- Hydrate is part of the dry frame and acts as cement in the grain contacts
- Presence of hydrate reduces the sediment porosity

Model D: Grain coating

- Hydrate is part of the dry frame
- Sediment porosity is reduced by the presence of hydrate



④ DEM Triaxial Tests

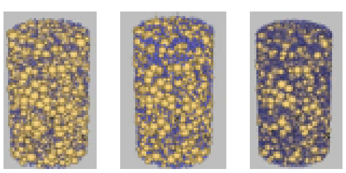


Fig. 4: DEM triaxial samples for 8%, 20% and 30% hydrate saturation

Sample preparation: Cylindrical and rectangular samples were created to simulate hydrate saturations ranging from 8% to 30% for the pore-filling case. (Fig. 4)

The particles were generated using the radii expansion method and the samples were subjected to isotropic consolidation previous to shearing.

Preliminary Results: Pore-filling case

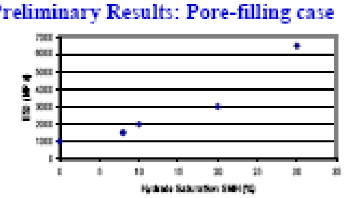


Fig. 5: DEM simulation: Effect of hydrate saturation (S_{MH}) on E_{50}

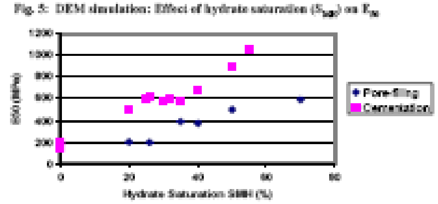


Fig. 6: Experimental data: Effect of hydrate saturation on E_{50} (Masui et al., 2005)

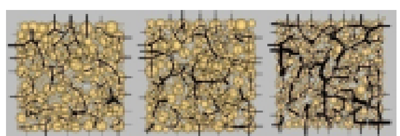


Fig. 7: Contact force distribution for hydrate particle diameters of 0.02mm, 0.04mm and 0.06 mm

Discussion: The preliminary DEM results follow the same trend as experimental results reported by Masui et al. (2005):

✓ Young's modulus (E_{50}) increases with S_{MH} (Fig. 5)

✓ The peak deviator stress depends on S_{MH}

✓ The rate of increase for E_{50} depends on S_{MH} and gas hydrate growth patterns (pore-filling or cementation) (Fig. 6)

✓ Enhanced dilation with increased S_{MH}

✓ The DEM results also show that an increase in hydrate particle size strengthens the contact force chain carrying the load within the sample (Fig. 7)

⑤ Future Work

This study will be extended to include:

✓ The different models of methane hydrate growth

✓ Sample creation following the probabilistic approach formulated by Santamarina et al. (2007) – heterogeneous nucleation of hydrates

✓ Compressibility simulated by DEM oedometer tests

⑥ References

✓ Klar A. & Soga K. (2005). "Coupled deformation-flow analysis for methane hydrate production by depressurized wells". Proc 3rd Biot Conference on Poromechanics

✓ Masui et al. (2005) "The effect of saturation degree of methane hydrate on the shear strength of synthetic methane hydrate sediments" Proc of 5th International Conference on Gas Hydrates. Trondheim, Norway

✓ Santamarina et al (2007) "Hydrate Bearing Sediments: Crystal Growth" In Publication

✓ Soga K., Lee S.L., M.Y. A. and Klar, A. (2006) "Characterisation and engineering properties of methane hydrate soils. Proc 2nd International Workshop on Characterisation and Engineering Properties of Natural Soils. 29 Nov-1 Dec, Singapore, Hight and Leroueil (eds.) Taylor & Francis Group Vol. 2591-2642

Casing Stability Modelling in Gas Hydrate Bearing Sediments

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Introduction:

Casing integrity in shallow marine sediments is challenging if natural gas hydrates exist in the sediments. In-situ hydrates could dissociate during deepwater drilling and production operation, resulting in an increase in pore pressure.

In this study, a numerical model is developed using ABAQUS (finite-element software) to model casing stability in gas hydrate bearing sediments. The model is developed by considering the interaction between the formation, the casing, and the cement with coupling the thermodynamic stability of the hydrates to hydraulic, mechanical and heat transfer terms.

It is assumed in the modelling that the permeability of gas hydrate bearing sediments is very low as a result the gas and water generated during gas hydrate dissociation cannot flow away and will increase pore pressure (i.e., to model the worst-case scenario) .

Numerical Modelling:

HWHYD, the Heriot-Watt Hydrate model, is used and implemented into the model to simulate hydrate stability zone and quantify the pore pressure increase due to gas hydrate dissociation. The effect of drilling fluid inside the casing has been taken into account by applying radial supporting force inside the casing with magnitude equal to drilling mud weight. It is assumed that there is a contact interaction between cement and formation but there is a perfect bond between the casing and the cement. All material properties used in the modelling were obtained from available literature.

Modelling Sequential:

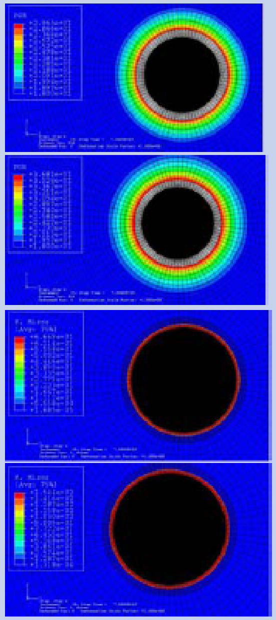
Equilibrium step:
In this step, the model is brought to equilibrium under in-situ stresses, temperature and pore pressure.

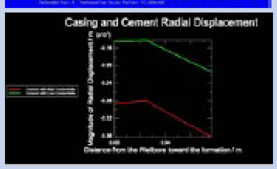
Drilling step:
To mimic actual drilling conditions and achieve the stress and displacement distribution around the wellbore during/after drilling, elements within the wellbore were removed from the model during this step.

Running the casing and cementing step:
In this step, it is assumed that casing is run and cemented immediately after drilling, hence after removing elements within the wellbore in the previous step, casing and cement elements were added to the model in this step to mimic casing running and cementing processes.

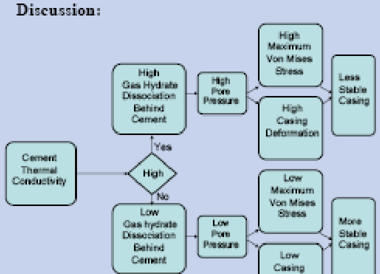
Drilling the next section step:
The temperature of casing elements in this step is increased by 10 K to model the heat transfer from drilling mud inside the casing.

Results:
The pore pressure increase due to gas hydrate dissociation, casing and cement radial deformation, maximum Von Mises stress generated after 8 days drilling of the next section of the wellbore with cement with two different thermal conductivities are shown in the following figures.





Discussion:



Conclusion:

A numerical model that couples a well-proven thermodynamic PVT-Hydrate model (i.e., HWHYD) with ABAQUS is developed. The model was used in investigating casing stability of wells drilled in gas hydrate bearing sediments in deep offshore environments. Under the assumed modelling and boundary conditions, it is found that the cement with low thermal conductivity decreases heat transfer from the wellbore towards the formation resulting in lower gas hydrate dissociation and lower pore pressure increase in the formation behind the cement. Maximum Von Mises stress generated in the casing with low thermal conductivity cement is lower than the wellbore with high thermal conductivity cement. As a result casing stability is higher in the wellbore cemented with the low thermal conductivity cement. It confirms the benefit of using cement with low thermal conductivity for cementing the gas hydrate bearing section in deep offshore wells.

The developed model can be used as a design tool to predict the casing stability and casing mechanical strength required for deep offshore wells drilled in gas hydrate bearing sediments.

Further development[1]:

1-Modelling Part:

1-1-Gas hydrate behind the cement sheath can also dissociate during setting and/or cementing, causing gas release which could result in delaying completion of the wellbore due to the flow of gas behind the casing or affecting the casing integrity or casing stability by creating voids (channels) in the cement sheath leading to non-uniform stress loadings.

We have investigated the casing stability of the deep offshore wellbore in the presence of void in the cement sheath (channeling)*.

*-" Finite Element Modelling of Casing in Gas Hydrate Bearing Sediments", Manoochehr Salehabadi, Min Jin, Jinhai Yang, Hooman Haghighi, Rehan Ahmed and Bahman Tohidi, accepted for publication and presentation at the 2008 SPE Europec/EAGE Annual Conference and Exhibition held in Rome, Italy, 9–12 June 2008

1-2- Numerical modelling of different scenarios associated with Geohazards of drilling deep offshore wellbore in gas hydrate bearing sediments (ongoing project)

2-Experimental Part:

Despite considerable interest in the properties of gas hydrate bearing sediments, the mechanical properties of these sediments remain poorly known. The mechanical properties and the constitutive model have a major effect on the results of the wellbore integrity modelling and also gas production from methane hydrates studies. Dissociation of methane hydrate in marine sediments may cause seabed subsidence or deformation of hydrate sediment strata. Such incident will directly affect the productivity of the producing wells if it is not properly estimated prior to the production. In this laboratory, we have conducted significant experimental work (through a joint industry project) on measuring the strength of gas hydrate bearing sediments as a function of various parameters, including hydrate saturation, sediment mineralogy, etc. Currently, we are installing the most advanced high pressure Triaxial testing setup designed for gas hydrate bearing sediments for conducting comprehensive study on the mechanical behaviour and properties of these sediments under realistic conditions.

1-Please do not hesitate to contact us if you are interested and required further details.

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Geomicrobial characterization of gas seep sediments using a novel molecular biological methods

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[1]Marine Biogeochemistry Section, Code 6114, U.S. Naval Research Laboratory, [2]Department of Environmental Science and Policy, George Mason University

ABSTRACT

Bacterial diversity in sediment cores from the mid-Chilean margin were studied using length heterogeneity-polymerase chain reaction (LH-PCR), and described in relation to *in situ* geochemical conditions. DNA from the sulfate-methane transition (SMT) of was analyzed by classic cloning and sequencing and by Multitag Pyrosequencing (MTPS). *Desulfosarcina* (*Dss.*) *variabilis* were found in all clone libraries and dominated one. *Dss. variabilis* related clones were similar to phylotypes observed at the SMT in association with anaerobic methane oxidation in the Eel River basin, Cascadia margin and the Gulf of Mexico. The LH-PCR amplicon associated with *Dss. variabilis* clones matched the amplicon that dominated most SMT samples, indicating environmental selection for *Dss. variabilis* relatives. Clones related to the Verrucomicrobia dominated the library for the methane gas containing core. Uncultured *Treponema* relatives dominated the library for the core obtained on the edge of a gas hydrate mound. The phylotypes that dominated clone libraries generally were observed when DNA was analyzed by MTPS and in most cases in similar proportion. However, due to the length of sequence reads by MTPS, some mismatches between sequences were found. The analysis of the two techniques demonstrated a high degree of agreement between MTPS and clone data but significantly greater depth of coverage of rare and dominant sequences by MTPS.

INTRODUCTION

Archaea and bacteria dictate the production and consumption of CH_4 in marine sediments around the world. An understanding of the composition of microbial communities involved in these processes is vital to understanding the contribution of marine CH_4 to the global carbon cycle. Along coastal margins CH_4 is either released to the water column or oxidized *in situ*. Archaea and sulfate reducing bacteria (SRB) are typically found in surface sediments above CH_4 seeps and gas hydrate beds at depths consistent with the anaerobic oxidation of methane (AOM).

Studies indicate that AOM is conducted via a metabolic partnership between by archaea known as ANME who oxidize CH_4 and SRB. Recent studies document dense cell masses of SRB surrounding clusters of ANME at depths where AOM occurs. This depth typically coincides with the sulfate-methane transition (SMT), where both SO_4 and CH_4 approach minimal concentrations due to biological consumption. Studies have identified relatives of the *Desulfosarcina* (*Dss.*) *variabilis* subgroup of SRB as key players in AOM. Specialized enzymatic systems that allow *Dss. variabilis* relatives and ANME groups to function in AOM in marine CH_4 seeps have not been identified. In the absence of these data there is an implied selection for phylogenetic groups in CH_4 charged sediments based on physical isolation or physicochemical criteria. Evidence is mounting that microbial communities in CH_4 seeps are similar regardless of location across large geographic distributions.

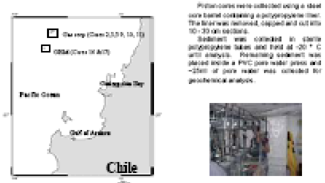
GOALS

Recent data indicates that the microbial community at the SMT is highly conserved (geographically), diverse but distinct from that located above and below. Due to the biological diversity of gas seep environments, it is important to use molecular biological that are capable of capturing the greatest amount of diversity possible in order to obtain an accurate description of phylotypes likely to be found in these environments. We will use three methods to probe at high resolution bacterial phylotypes in methane charged sediments and determine if MTPS analysis is suitable for these types of samples.

METHODS

Study location and sample collection

Sampling occurred aboard the OSV Vidal Gormaz along the mid-Chilean margin, NW of Concepción, in October 2004. An area containing sediment blanking zones indicative of a gas seep and a gas hydrate mound (GHM) were sampled.



Piston cores were collected using a steel core barrel containing a polypropylene liner. The liner was removed, capped and cut into 10 - 20 cm sections.

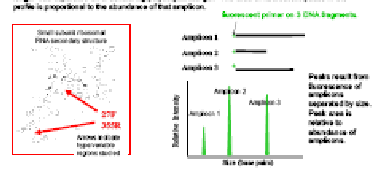
Sediment was collected in sterile polypropylene tubes and held at -20 ° C until analysis. Remaining sediment was placed inside a PVC pore water press and ~25ml of pore water was collected for geochemical analysis.

Geochemistry

Sulfate and chloride were determined using an ion chromatograph and quantified against diluted IAPSO standard seawater. Total dissolved sulfides (TDS) were determined spectrophotometrically according to the Cline method. Dissolved inorganic carbon (DIC) was determined coulometrically and quantified against certified reference seawater standards. Methane was analyzed using GC equipped with a flame ionization detector. DIC and Methane stable carbon isotope ratios (δ13C) were measured using a Trace GC and a GC-C III interface to oxidize compounds after separation and Delta Plus XP IRMS for isotopic analysis.

Length-Heterogeneity PCR (LH-PCR)

Genomic DNA was extracted using the Bio 101 FastDNA ® SPIN kit for soil. 10 ng of DNA was used as template for triplicate LH-PCRs. LH-PCR characterizes bacterial communities by amplifying variable regions of 16S rRNA genes of individual phylotypes. PCR amplification of the first two variable regions of the SSU-rRNA was performed using a fluorescently labeled (27F-6-FAM) forward primer and a non-fluorescent reverse primer (355R). Natural variation in amplicon length was separated on a denaturing polyacrylamide gel. The area of fluorescent peaks in the profile is proportional to the abundance of that amplicon.



Cloning and Sequencing

LH-PCR fragments were cloned using a TA cloning kit and sequenced on a SCE9610. Sequence data was submitted for MEGABLAST searches against GenBank (NCBI) and the Ribosomal Database Project (RDP).

Custom PERL scripts were used to blast sequence data against the RDP, identify clones, tabulate results, calculate diversity, and construct rarefaction curves. Typically, Genbank searches using BLAST identify uncultured environmental clones with little phylogenetic data. We used a novel approach and performed BLAST analysis on the RDP and associated the highest hit with a RDP number derived from a hierarchical classification system based on the multiple alignment of all know SSU rDNA in Genbank.

Clone data, the RDP hit, and the putative ID was stored in associative array and saved as a Genetic Data Environment formatted database. The clone libraries were analyzed using rarefaction analysis to determine the estimated diversity of the phylotypes in the community. Clone sequences were aligned using Clustal X and a phylogenetic tree was constructed using PAUP.

LH-PCR was conducted on sequenced clones to match amplicon length with clone identities.

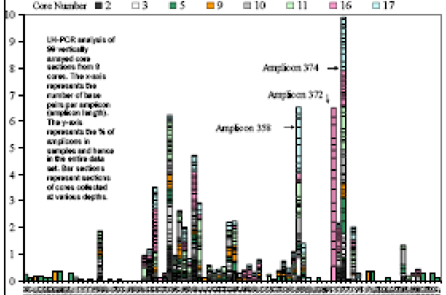
Multi-Tag Pyrosequencing (MTPS)

Multitag Pyrosequencing, a new implementation that allows for the acquisition of in depth coverage of multiple environmental samples was utilized to analyze bacterial communities. MTPS technology takes individual DNA molecules and amplifies them on beads using an oil emulsion PCR technique. The individual bead-DNA moieties were sequenced in picolitre reactions. 454 Life Sciences provides a custom service for pyrosequencing and has a protocol which allows 10 samples to be processed at a time. The process generates sequences of ~100 bases in length. A single run yields ~1 million bases of data from 10,000 templates in each sample reaction. A set of ten universal 16S rDNA primers were generated and used to tag DNA fragments on the 5 prime end with a 4 base "barcode". PCR was performed on individual samples using the barcoded primers and then 10 samples were pooled and ligated to pyrosequencing beads. The samples were pyrosequenced as above except that 10 separately tagged environmental samples were pooled in each single run. The data were deconvoluted by sorting the sequences into bins based on the barcodes.

Following MTPS, sequence data was submitted for MEGABLAST searches against GenBank and the RDP.

RESULTS AND DISCUSSION

LH-PCR Analysis of All Cores



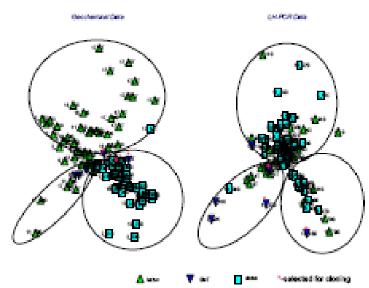
*Amplicon 373.8 was ubiquitous in the dataset and observed in 65% of samples.

*Amplicon 358.0 was observed only at or within 10 cm of the SMT in samples from the seep area.

*The majority (up to 70%) of amplicon data in some SMT samples (e.g., cores 3, 10 and 11) was accounted for by by amplicon 358.0 indicating an elevated presence of the phylotype represented by this amplicon.

*Amplicon 358.0 was observed at multiple depths in Core 17 (GHM). Core 17 had the highest gas flux to the surface.

*Amplicon 371.8 was only observed in sections from Core 16 despite the fact that Core 16 was obtained from a location < 1 km from Core 17



Non-Metric Multidimensional Scaling analysis (MDS) was used to display the structure of distance-like data as a geometrical picture for geochemistry and LH-PCR data. MDS displays the structure of distance-like data as a geometrical picture and depicts the approximate distances between pairs based on similarity analysis (Euclidian). This technique was used to determine groupings in the data based separately on geochemistry and LH-PCR data and assist in sample selection for sequencing by two methods.

Geochemistry Data: Three groups were evident. Samples above and below the SMT clustered in separate groups. Some SMT samples aligned along the intersection of the clusters. A third group which main consisting of samples from cores 11 and 17, those with the highest free gas concentration clustered together. This cluster also included several SMT samples.

LH-PCR Data: Three groups were evident but with the exception of the group that contained the majority of SMT samples, these did not align with geochemical data. There was no clear distinction between samples collected above and below the SMT. Samples from the gas seep area generally clustered together. Samples from core 16 taken on the flanks of the GHM formed a distinct cluster, and samples from the SMT generally clustered with samples from core 17 taken on the GHM.

Sample	# of MTPS sequences	# clones	# of phylotypes (MTPS)	# phylotypes (clone)
[illegible]	[illegible]		[illegible]	
[illegible]	[illegible]		[illegible]	
[illegible]	[illegible]		[illegible]	
[illegible]	[illegible]		[illegible]	
[illegible]	[illegible]		[illegible]	
[illegible]	[illegible]		[illegible]	
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[illegible]	[illegible]		[illegible]	
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[illegible]	[illegible]		[illegible]	
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[illegible]	[illegible]		[illegible]	
[illegible]	[illegible]		[illegible]	
[illegible]	[illegible]	79	[illegible]	[illegible]
[illegible]	[illegible]		[illegible]	
[illegible]	[illegible]		[illegible]	
[illegible]	[illegible]		[illegible]	
[illegible]	[illegible]	79	[illegible]	[illegible]
[illegible]	[illegible]		[illegible]	
[illegible]	[illegible]		[illegible]	
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[illegible]	[illegible]		[illegible]	
[illegible]	[illegible]		[illegible]	
[illegible]	[illegible]	79	[illegible]	[illegible]
[illegible]	[illegible]		[illegible]	
total	[illegible]	[illegible]	[illegible]	[illegible]

Comparative Analysis if SMT Samples Using Two Methods

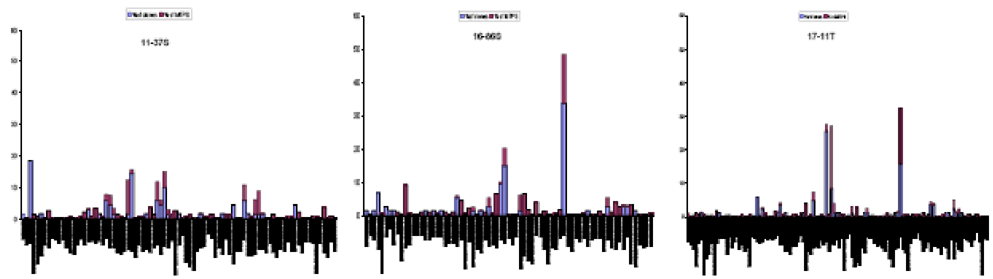
*δ-proteobacteria accounted for 30% of the clone library and 50% of MTPS sequences of samples 11-37S, 16-86S and 17-11T collected from the SMT. A relative of *Desulfosarcina* (*Dss.*) *variabilis* which matched ≥98% with clones obtained from CH_4 charged sediments from the Cascadia Margin and Gulf of Mexico was found in all samples and accounted for the majority δ-proteobacteria clones.

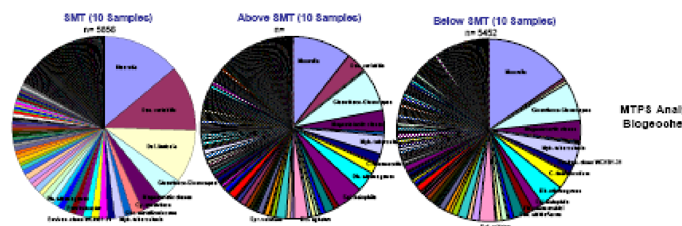
*The *Dss. variabilis* related clone was a major phylotype in all three clone libraries; MTPS analysis indicated that it accounted for only 10% of sequences in samples 11-37S and 16-86S, and 37% of sequences in sample 17-11T.

*The *Dss. variabilis* related clones matched amplicon 358, which is the amplicon most abundant at the SMT in all cores. A relative of *Moorella glycerini* (*Thermoanaerobacter*) was abundant in all cloned samples and most abundant in sample 17-11T. The frequency of *Moorella* related clones was similar to that of MTPS data for samples 11-37S and 17-11T, however, *Moorella* related MTPS sequences were less prevalent compared to clone sequences in sample 16-86S. The majority of *Moorella* related clones and MPTS sequences were related (≥93%) to uncultured JS1 candidates commonly observed in marine sediments adjacent to CH_4 seeps.

*Amplicon 374 matched with a relative of the JS1 candidates commonly observed in CH_4 charged marine sediments.

*Sample 16-86S was less diverse than the other cloned samples. *Treponema* related clones infrequently observed only in deep sea marine sediments near GHMs dominated the library. The LH-PCR amplicon of this clone was 372 consistent with the amplicon observed only in Core 16. The MPTS analysis of 16-86S did not reveal *Treponema* sequences, however, some related *Spirochaete* sequences were observed.





MTPS Analysis of Three Biogeochemical Zones

*Sequences of Moorella related to JSI candidates dominated all three biogeochemical zones indicating their ubiquity in sediments adjacent to marine CH_4 seeps.
* *Dss. variabilis* related sequences accounted for 11% of ~7000 MTPS sequences of samples collected from the SMT in all cores and were significantly less abundant in samples above and below the SMT. The *Dss. variabilis* relative observed in this study has been observed in numerous marine CH_4 seeps around the world. The conditions at the SMT appear to select for elevated concentrations of this organism. If the *Dss. variabilis* relative was involved in organoclastic sulfate reduction its abundance above the SMT (e.g. the sulfate reduction zone) is expected to be higher. However, its concentrated presence at the SMT indicates its involvement in sulfate reduction coupled to AOM.
*Community composition above and below the SMT in the 8 cores studied was similar with the most notable difference being the higher abundance of *Dss. variabilis* related sequences above the SMT in the sulfate reduction zone.
*MTPS is a highly useful tool for profiling at high resolution microbial communities in deep marine sediments.

Shallow Sediment Carbon Cycling Driven by Deep Methane Vertical Flux: Atwater Valley on the Texas-Louisiana Shelf

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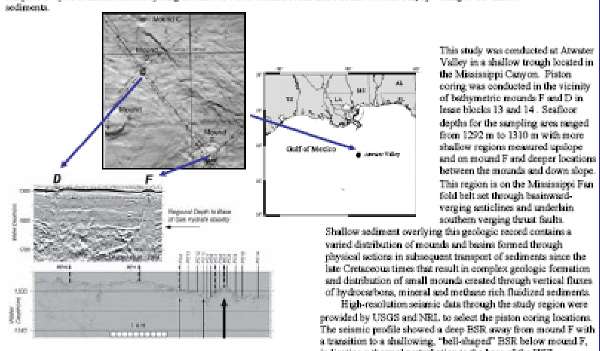
Abstract

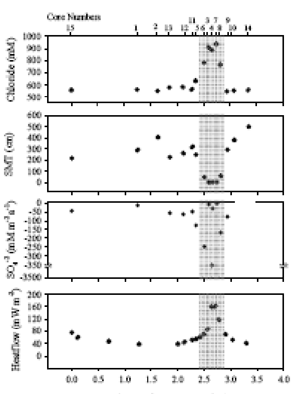
The contribution of deep sediment methane (CH_4) to shallow sediment carbon cycling was studied on the Atwater Valley, located at a water column depth of 1,292 to 1,310 m, south of the Mississippi Delta, on the Texas-Louisiana Shelf. Sediment porewater geochemical data (SO_4^{-2}, CH_4, DIC, $\delta^{13}C$-DIC and Cl^-) were obtained in cores collected in a transect moving across a mound that was characterized with heatflow and seismic data. The sulfate methane transition (SMT) ranged from 0 to 504 centimeters below the sea floor (cmbsf). The shape of porewater SO_4^{-2} profiles plotted against depth also varied across the transect from linear to non-linear. Diffusion rates estimated from linear SO_4^{-2} concentration gradients ranged from -13.4 to -249.1 mmol m^{-2} s^{-1} with the greatest rate measured in sediments on a mound that was the focus for this study.

Stable carbon and radiocarbon isotope analyses on a variety of organic and inorganic carbon pools are interpreted for spatial variation of shallow sediment carbon cycling. High vertical methane fluxes were observed on top of a mound where seismic data indicated a vertical rise in the BSR and heatflow suggested active fluid and gas fluxes. On the mound the vertical CH_4 flux inhibited downward SO_4^{-2} diffusion. Off the mound the maximum downward SO_4^{-2} diffusion depth was approximately 4 meters. Stable carbon isotope values for CH_4 as well as the gas composition indicates a microbial CH_4 source, with $\delta^{13}C$ values in core gas pockets over the mound averaging -71.65 ± 0.93‰ (n=12) and CH_4 the dominant sediment gas with an average C1/C2 ratio of 10,477. Results from the carbon isotope analysis indicate ocean water column phytoplankton to be a dominant contribution to the sediment carbon cycling over off the mound with shallow organic sediment $\Delta^{14}C$ at -283‰ and $\delta^{13}C$ averaging -22.5 ± 0.6‰. In contrast, on the mound, $\Delta^{14}C$ of the organic sediment ranged from -955‰ to -890‰ and $\delta^{13}C$ was lower with an average of -25.8 ± 0.8‰. This indicates that CH_4 is the primary carbon cycle on the mound. A thorough comparison of $\Delta^{14}C$ and $\delta^{13}C$ in different carbon pools between locations indicates that the primary carbon cycles in the shallow mound sediments are AOM and CO_2 fixation. These data contribute to understanding of variation in non-conservative versus linear SO_4^{-2} profiles observed across the seismic line. In addition, this data provides a unique survey of sediment carbon cycling in terms of water column sedimentation and vertical CH_4 upwelling to the shallow sediments.

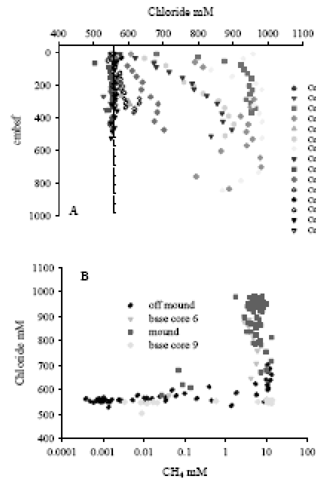


This study was conducted at Atwater Valley in a shallow trough located in the Mississippi Canyon. Piston coring was conducted in the vicinity of bathymetric mounds F and D in lease blocks 13 and 14. Seafloor depths for the sampling area ranged from 1292 m to 1310 m with more shallow regions measured upslope and on mound F and deeper locations between the mounds and down slope. This region is on the Mississippi Fan fold belt set through basinward-verging anticlines and underlain southern verging thrust faults. Shallow sediment overlying this geologic record contains a varied distribution of mounds and basins formed through physical actions in subsequent transport of sediments since the late Cretaceous times that result in complex geologic formation and distribution of small mounds created through vertical fluxes of hydrocarbons, mineral and methane rich fluidized sediments.

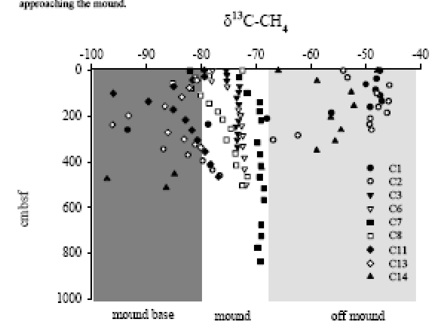
High-resolution seismic data through the study region were provided by USGS and NRL to select the piston coring locations. The seismic profile showed a deep BSR away from mound F with a transition to a shallowing, "bell-shaped" BSR below mound F, indicating a thermal perturbation to the base of the HSZ suggesting upward fluid advection. Heatflow data across the coring region was consistent with shallowing of the seismic profile and the conclusion of upward fluid advection below mound F.



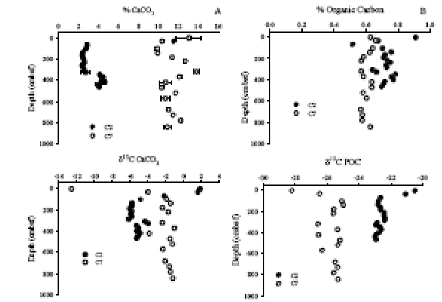
The seismic profile showed a deep BSR away from the mound with a transition to a shallowing, "bell-shaped" BSR on the mound, indicating a thermal perturbation to the base of the HSZ and possible upward fluid flux. Heatflow data across the coring region was consistent with shallowing of the seismic profile and supported interpretation of upward fluid flux. Piston cores were collected along a 3.5 km transect on, at the base and off the mound. The sulfate methane transition (SMT) was determined in each core from porewater SO_4^{-2} and CH_4 concentration profiles and occurred at depths ranging from 0 to 410 centimeters below the sea floor (cmbsf). The shape of porewater SO_4^{-2} profiles plotted against depth also varied across the transect from linear to non-linear. Diffusion rates estimated from linear SO_4^{-2} concentration gradients ranged from -13.4 to -249.1 mmol m^{-2} s^{-1} with the greatest rate measured in sediments on the mound. The large variation in SMT depth and SO_4^{-2} profiles across the transect indicates lateral differences in total vertical CH_4 flux between locations. Results suggest steady state and non-steady state CH_4 fluxes both on the mound and transitioning off the mound and likely differences in the relative contribution of fluid advection to local shallow sediment CH_4 cycling. Cores collected from on the mound had high porewater headspace CH_4 concentrations (up to 8.34 mM) coupled with elevated Cl^- concentrations (up to 956.5 mM) at shallow depths suggesting that salt diapirism in deep sediments may be decreasing hydrate stability and increasing vertical CH_4 flux.



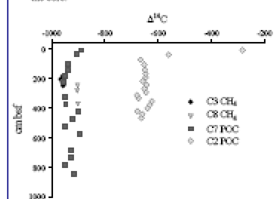
Elevated porewater Cl^- was observed above the seawater background in a distinct spatial distribution between cores off the mound, at the base, and on the mound. Where high Cl^- concentrations were measured, there frequently were high dissolved CH_4 concentrations suggesting decreased hydrate stability from locally elevated salt concentrations. The trend at Atwater Valley of high Cl^- concentrations and elevated CH_4 concentrations on the mound, to intermediate CH_4 and Cl^- concentrations at the mound base, and to seawater background Cl^- concentrations and low CH_4 away from the mound would be consistent with a decrease in the thickness of the hydrate stability zone approaching the mound.



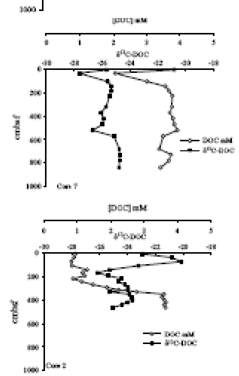
The range of $\delta^{13}C$ values for CH_4 in core gas pockets was -79.9‰ to -63.7‰ with an average of -71.3 ± 3.3‰ (n=21), indicating a microbial source. The headspace $\delta^{13}C$-CH_4 profiles taken through the transect show a large horizontal and vertical variation in the $\delta^{13}C$. Vertical porewater CH_4 profiles of cores 3 and 7 from the mound varied little throughout the core with an average $\delta^{13}C$ of -73.7±0.9‰ (n=14) and -70.4±0.3‰ (n=16), respectivley. The most ^{13}C enriched core samples, -45.8 ‰ to -54.9 ‰, coincided with the lowest CH_4 concentrations in shallow segments of cores, at or below 0.01 mM in cores 1, 2, and 14, located over the BSR. Another common data pattern through all cores, except those taken on the mound, was depleted ^{13}C CH_4 relative to on the mound porewater and gas samples. These values, down to -96.2 ‰, were observed in samples taken from the mid core porewater depths, just below the SMT.



In this study core 2 (off the mound) and core 7 (on the mound) were compared for differences in the shallow sediment carbon cycling. Percent organic carbon through core 7 averaged 0.60 ± 0.03% (n=16) and 0.72 ± 0.07% (n=19) for core 2. $\delta^{13}C$ values of the organic sediment in these two cores ranged from -23.0 to -20.5 ‰ in core 2 and -28.2 to -25.0 ‰ in core 7. The profiles of $CaCO_3$ percent carbon and $\delta^{13}C$ for core 7 on the mound, relative to core 2 off the mound were considerably different; average percent $CaCO_3$ was 11.4 ± 1.1 % in core 7 and 4.1 ± 3.0 % in core 2, while $\delta^{13}C$-$CaCO_3$ ranged from -6.1‰ to 1.8‰ and -12.6‰ to -1.1‰ for cores 2 and 7, respectively. $\delta^{13}C$ in core 7 was relatively constant except for near the sediment water column interface were there was a rapid decrease. In contrast, core 2 was enriched in ^{13}C in the surface and depleted in the deeper section of the core.



$\Delta^{14}C$ for CH_4 was measured on gas pocket samples taken from cores 3 and 8 on top of the mound. The $\Delta^{14}C$ of gas CH_4 from core 3 averaged -960.8 ± 3.16 ‰ (n=7) in two pockets collected at 180 and 246 cmbsf. These data were averaged to represent $\Delta^{14}C$ of the deep gas source of CH_4 in this region. From core 8, located nearby on the mound core gas was enriched in ^{14}C relative to core 3 with an average $\Delta^{14}C$ value of -903.0 ± 1.82‰ (n=3) at 240 to 363 cmbsf. $\Delta^{14}C$ for organic sediment in core 2 ranged between –679‰ to –283‰, with significantly higher (more modern) signatures measured in shallow sediments. Core 7 was substantially more depleted in ^{14}C with a range in ratios from –955‰ to –890‰. In core 7 a slightly younger signature (-890‰) was present near the surface sediment.



Porewater DOC concentration and $\delta^{13}C$ provides additional interpretation of the shallow sediment organic carbon cycling. On the mound the porewater DOC profile was relatively flat at approximately 4 mM with sharp decline toward 2 mM near the sediment-water column interface. Off the mound the porewater DOC concentrations were at a similar concentration below the SMT and declined to around 1 mM above the SMT. A large difference in the $\delta^{13}C$ DOC was observed between on mound and off mound cores. Substantially ^{13}C depleted DOC was observed through the mound core porewater, with a range from -27.7‰ to -25.4‰. In contrast, the $\delta^{13}C$ DOC through core 2 was ^{13}C enriched with a range of -26.1‰ to -23.5‰ below the SMT and -20.1‰ to -23.4‰ above the SMT. These data indicate that primary production was the dominant source of porewater DOC in the shallow subsamples above the SMT in core 2 and a CH_4 driven carbon cycle contributed to the DOC pool below the core 2 SMT and to a large extent through the entire core 7. These data support the interpretation of organic sediment stable carbon and radiocarbon isotope ratios for high vertical CH_4 flux on the mound driving the shallow sediment carbon cycling.

Summary

- Salt diapirs create unstable hydrate deposits in the deep sediment that result in a greater vertical methane flux.
- Shallow sediment DIC concentrations and stable carbon isotope analysis indicates a more active microbial respiration on the mound where a higher vertical methane flux is observed.
- Radiocarbon isotope analysis suggests that the methane is responsible for enhance production of shallow sediment organic carbon.
- DOC concentrations and stable carbon isotope analysis indicates higher production of organic carbon that is associated with the elevated vertical methane flux.

6th International Methane Hydrate Research and Development Workshop, Bergen Norway, 12-15 May, 2008

Geochemical and geophysical data integration for preliminary hydrate surveys across the Porangahau Ridge on the Hikurangi Margin, New Zealand

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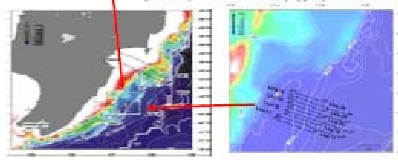
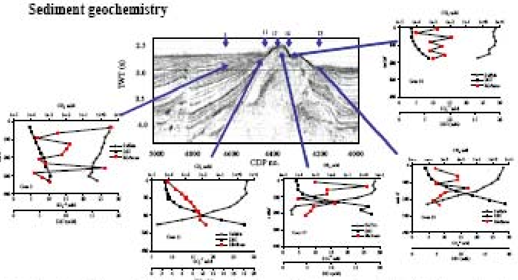
Abstract

Porangahau Ridge is located offshore of the Wairarapa, in northeastern New Zealand coastal waters. In this region a suspected gas chimney has been observed in seismic data, potentially indicating a deposit of highly concentrated gas hydrates. Potential gas hydrate deposits were outlined with bottom simulating reflections in seismic data on the Porangahau Ridge, landward of the Hikurangi Channel. There was an observation of elevated amplitudes in the gas hydrate stability zone beneath several anticlines. Beneath one of the anticlines, across the Porangahau Ridge, a prominent high-amplitude reflection band extends from a BSR to about halfway to the seafloor. Geochemical analyses of shallow sediment porewater profiles and vertical fluid migration measured with heatflow probing were compared with regions of seismic profiles identified with potential gas hydrate "sweetspots". Spatial orientation of piston coring and heatflow probing was organized to compare vertical methane fluxes along the seismic profiles, with focus on the predicted sweetspot, across the ridge. During the subsequent cruise, SO191, a CSEM (controlled source electromagnetic) survey was conducted across the primary geochemical and heat flow study site. These data sets are compared for the potential application to coastal ocean methane hydrate surveys.

The cruise (TAN0607) was a collaboration between GNS Science, the U.S. Naval Research Laboratory, the National Institute of Water and Atmospheric Research, the Universities of Otago, Hawaii, and Rochester (New York), as well as individual scientists from as well as individual scientists from the University of Auckland and the GeoForschungsZentrum Potsdam. This expedition was the first research campaign dedicated to application of geochemistry and seismic data for studying gas hydrates on the Hikurangi margin.

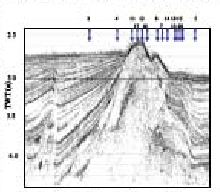


Sediment geochemistry

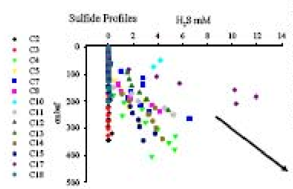


These data provide a spatial representation of the porewater sulfate-methane profiles taken across the seismic profile line. A comparison of the vertical variation in methane and sulfide results in inverse concentration gradients, with declines in sulfate from reduction to sulfide coinciding with increases in the DIC upon anaerobic methane oxidation. The concentration of DIC follows the sulfate profiles with the variation in the vertical methane diffusion across the seismic line. DIC data are presented as an estimate of the sulfate reduction and subsequent methane oxidation because of the generally low methane concentrations (near the limits of detection) measured in the cores. Core 3 was taken on the landward side, well off the ridge, in a region with a level BSR observed in the seismic profile. The shallow porewater sulfate profile in this core suggests a low vertical methane flux in this region. Similar sulfate and methane profiles were measured in Core 18, located near the top of the Porangahau Ridge. This profile results from low vertical porewater and methane flux, perhaps impeded by carbonate formation on the mound. Rapid vertical methane diffusion was observed in the sulfate and methane profiles at the coring locations on the landward side (Cores 11 and 17), and seaward side (Core 13) of the ridge. The shallow SMI observed in Cores 11 and 17 match the location for the elevated CSEM data presented in subsequent graphs. These profiles are used to estimate the SMI and sulfate flux through the geochemical transect; presented below.

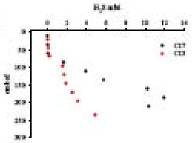
Core	SMI (cm)	Flux (mmol SO_4 m^{-2} a^{-1})
2	3951	-4.16
3	1287	-11.36
4	443	-53.34
5	364	-58.25
7	211	-74.18
8	357	-44.78
10	67	-206.56
11	189	-71.36
12	n.d.	no gradient
13	268	-73.79
14	381	-41.46
15	443	-56.78
17	184	-86.17
18	986	-25.65
28	323	-60.56
29	335	-74.85
30	383	-58.56
31	945	-26.28
32	654	-31.45

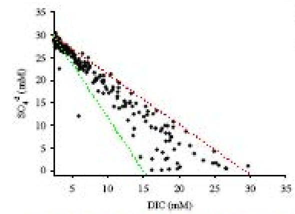


Vertical porewater sulfate and methane profiles showed a range for the sulfate-methane interface (SMI) between 12.9 m upslope and 1.84 m near the ridge. The deepest measured SMI was at the nearshore control region at 39.5 m. Vertical sulfate fluxes through this transect were consistently diffusive with a range of -4.2 mM m^{-2} a^{-1} upslope, way from the ridge, and up to -206.6 mM m^{-2} a^{-1} on the ridge. On the landward side of the Porangahau Ridge transect the deepest SMI was 12.9 m and -11.4 m^{-2} a^{-1} for the vertical sulfate diffusion. Moving toward the slope of the ridge peak the SMI was substantially shallower and sulfate diffusion greater with values of 1.84 m and -86.2 m^{-2} a^{-1}, respectively in Core 17. A similarly shallow SMI, 2.11 m, was measured on the seaward side of the ridge at Core 7. In Core 7 the sulfate diffusion rate was -74.2 m^{-2} a^{-1}. Geochemical porewater profiles did not provide a sulfate gradient on top of the ridge (Core 12).



Sulfide concentrations in porewater follow the sulfate and methane profiles resulting from methane oxidation during sulfate reduction, showing elevated concentrations in the mid and deep core subsamples. Sulfide concentrations were below the limits of detection on the ridge and at the landward site. An interesting comparison of the sulfide profiles is the large difference in the concentration gradients between the landward and seaward cores that had similar sulfate profiles. In comparison of these two profiles the higher sulfide end product in the sulfate reduction suggests a greater anaerobic methane oxidation at the landward coring locations. This observation supports the heatflow data presented below with active fluid advection on the landward side of the ridge and diffusion on the seaward point.



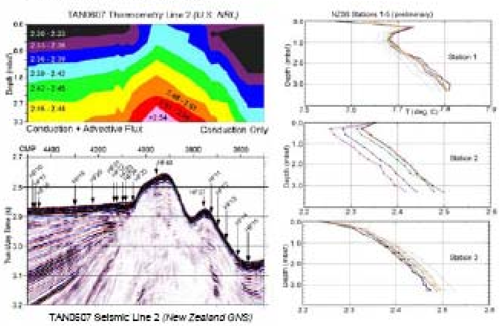


$$2(CH_2O) + SO_4^{2-} \rightarrow 2HCO_3^- + H_2S - \text{Organoclastic SR}$$

$$CH_4 + SO_4^{2-} \rightarrow HCO_3^- + HS^- + H_2O - \text{AOM}$$

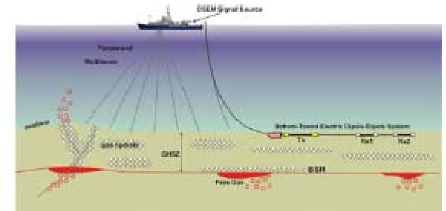
Porewater sulfate reduction in shallow sediments occurs through anaerobic oxidation of methane (AOM) that is coupled with sulfate reduction (SR) and/or through organoclastic SR. Differentiation between these two cycles in the sulfate reduction assists in the interpretation of deep sediment vertical methane migration. With a linear profile in the sulfate gradient AOM can be assumed and the vertical methane diffusion can be estimated. A comparison of the porewater sulfate and DIC profiles expected for AOM and organoclastic SR shows that this region on the Hikurangi Margin had a significant contribution from organoclastic SR. These data need to be considered for prediction of the deep sediment methane concentrations.

Sediment porewater heatflow

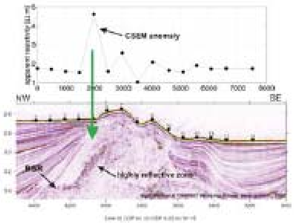


For this study heatflow data is compared with the seismic profiles, porewater geochemical parameters and electromagnetics to identify regions through the transect with active vertical methane and fluid diffusion and advection. Heatflow data suggest vertical fluid advection on the landward side of the mound and low vertical fluid fluxes on the seaward side. These data show a major thermal perturbation associated with the accretionary margin fold on the landward side of the ridge. However, unlike a single seafloor seep, there does not appear to be significant flux associated with the fold itself. Most of the thermal profiles exhibit linear character suggesting minimal if any fluid advection. The exception is the profiles on the landward side of the ridge, where concave downward character is indicative of fluid advection.

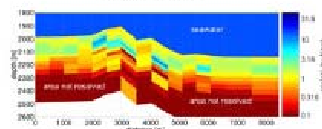
Electromagnetics



On cruise SO191, a unique bottom towed electric dipole-dipole system was used to study New Zealand's gas seep sites and gas hydrates along the same geochemical/seismic survey line. The electrical resistivity of marine sediments depends on the porosity, and the conductivity and connectivity of pore fluid, i.e. seawater. Hydrate formation reduces the effective sediment porosity and thus causes a higher observed resistivity where hydrate forms in sufficient quantities. Two receiving dipoles Rx1 and Rx2 (15m each) are towed behind a transmitting dipole Tx (136m). The source signal is generated by a current transmitter on the ship and is sent down to the Tx via the coaxial cable. The electromagnetic disturbance propagates away from the Tx through the seawater and the sediments and is recorded at the receivers at a distance of 387m (Rx1) and 705m (Rx2). Signal form and amplitude depend on seafloor conductivity structure. However, because of the large distance to Rx2 the signal to noise ratio was to small, thus no data from Rx2 have been used in the analysis.



An apparent resistivity profile was obtained along line (top profile) which is consistent with the geochemistry/heatflow seismic line 02 (middle profile) collected during TAN0607. The 1D layered modeling (bottom profile) reveals high resistivity along a line in the region where seismic data suggest a vertical gas and fluid flux that is coupled with heatflow and geochemical profiles. The cause for the anomalous resistivity is presumably due to an enriched gas hydrate concentration beneath the vents. This is based on the belief that free gas is transported through the GHSZ by percolation or along faults and fissures which act as pathways for uprising fluids where the gas flow can be continuous. Based on theoretical resistivity porosity relation, a higher gas hydrate concentration at depth beneath the seeps seems to be a better candidate than free gas to explain the observed CSEM anomalies, but gas may also play a role.



Summary

This study combines seismic data, porewater geochemical profiles, heatflow and CSEM to evaluate deep sediment methane across the Porangahau Ridge, on the Hikurangi Margin. The primary observations of this data summary include:

1. Identification of regions with active shallow geochemical profiles on and at the base of the Porangahau Ridge that coincide with seismic blanking observed on the landward side of the ridge.
2. Evidence in the porewater geochemistry profiles that indicates substantial organoclastic SR that needs to be considered in the prediction of the deep sediment vertical methane fluxes.
3. Advective heatflow data that coincides with the shallow geochemical profiles and seismic blanking.
4. A strong coupling of the seismic, porewater geochemistry and heatflow data with the CSEM data on the landward base of the Porangahau Ridge.
5. The combination of these data provides the capability to couple seismic profiles, porewater geochemistry, heatflow and CSEM to survey deep sediment methane and the potential vertical hydrate distribution for a quantitative prediction of sediment hydrate loading.

6th International Methane Hydrate Research and Development Workshop, Bergen Norway, 12-15 May, 2008

Deformation of methane hydrate supported sand during its dissociation

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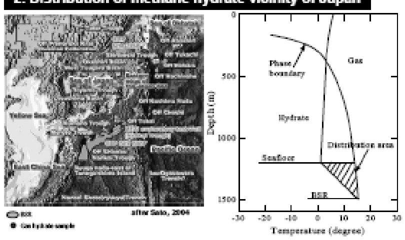
1. Back ground

Methane hydrate is currently being eagerly examined as a next-generation energy resource to replace oil and natural gas.

It is estimated that the methane hydrate reserves around Japan, a nation otherwise poor in energy resources, would be sufficient to last over 100 years, based on present levels of natural gas consumption• •

To develop this new, unfamiliar resource, Advisory Committee for National Methane Hydrate Exploitation Program, an investigative committee established within the Ministry of Economy, Trade and Industry has prepared "Japan's Methane Hydrate Exploitation Program".

2. Distribution of methane hydrate vicinity of Japan

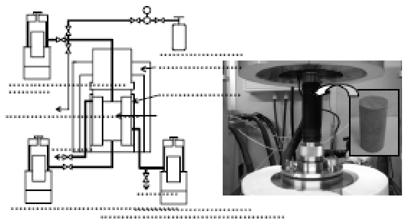


3. Purpose of the study

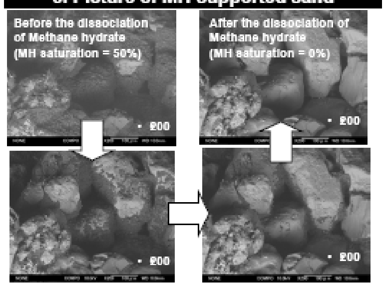
1. Formation of methane hydrate in the sand specimen in triaxial cell
2. Triaxial compression tests on the methane hydrate-bearing sand at the same condition as deep seabed
3. Deformation of the specimen due to decomposition of methane hydrate

4. Testing Equipment

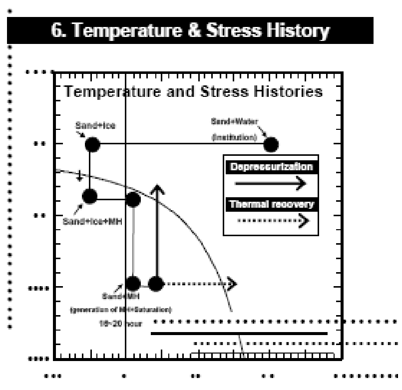
Maximum cell pressure• •
max 30MPa
Maximum back pressure• •
max 20MPa
Maximum axial load• •
max 200kN
Temperature• •
-35• 60• •



5. Picture of MH-supported sand

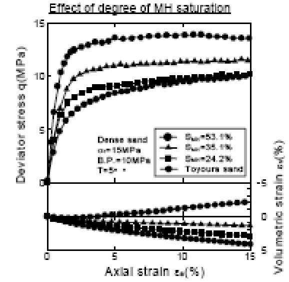


6. Temperature & Stress History



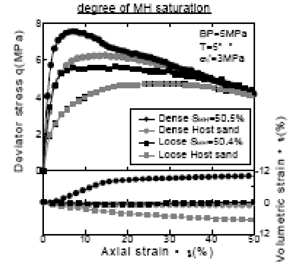
7. Triaxial behavior of MH-supported sand

Effect of degree of MH saturation



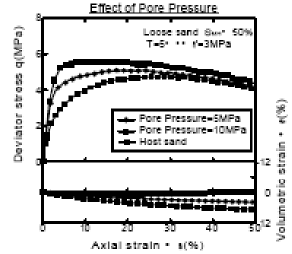
The experimental results with changing degree of MH saturation are shown. Based on the figure, an increase in the axial deviator stress is observed with the increase in degree of MH saturation. It is believed that as the proportion of MH occupying the pores is increased, the cementing force also increased, resulting in MH adhering firmly in-between the sand particles. Moreover, higher degree of MH saturation results in higher residual strength.

Difference in residual strength due to different degree of MH saturation



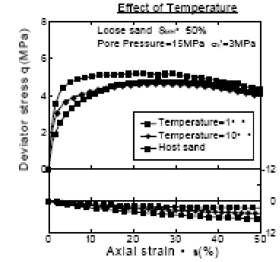
Shear test results up to 50% axial strain is shown. For sands containing MH, the cementing strength gradually decreases as the peak strength is approached, and the strength decreases. However, it is believed that even when the cementing force is lost, MH is still present inside the pores.

Effect of Pore Pressure



The test results for various pore pressures under similar effective confining pressure, temperature and S_{MH}. From the results, an increase in the axial deviator stress was observed with the increase in pore pressure. Thus, the strength of sand containing MH depends on depth, with an increasing strength associated with increasing depth. Similar dependence with temperature and back pressure were observed in previous experiments involving MH only and, therefore, the present results on MH trapped within sand particles support such findings.

Effect of Temperature

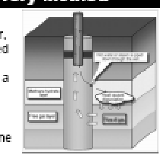


The axial deviator stress-axial strain-volumetric strain relations for the cases where the temperature was varied between 1oC and 10oC are shown. It is understood from the figure that specimen under 1 oC shows higher strength when MH saturation is approximately same.

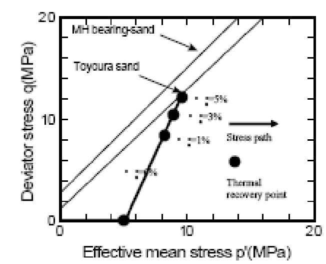
8. Deformation of the sand specimen due to dissociation of methane hydrate

8.1 Thermal Recovery Method

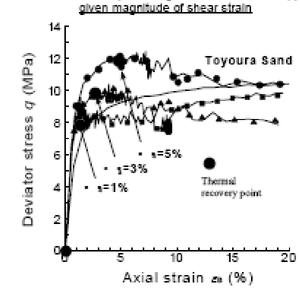
In this method, a well is drilled to the methane hydrate-bearing layer, and methane hydrate is dissociated by heating using a fluid (hot water or steam) heated at the surface in a boiler or similar device and circulated down through the well. This causes methane hydrate to decompose and generates methane gas.



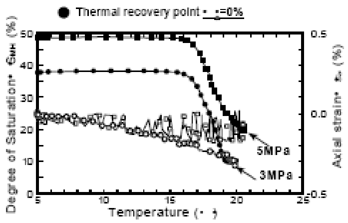
Rupture envelope of MH bearing-sand and Toyoura sand



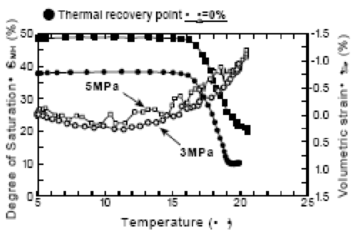
Deformation of sample during dissociation of MH applied given magnitude of shear strain



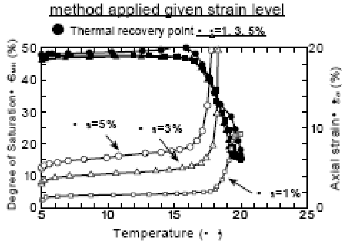
Axial strain developed during dissociation of MH at isotropic stress condition by thermal recovery method



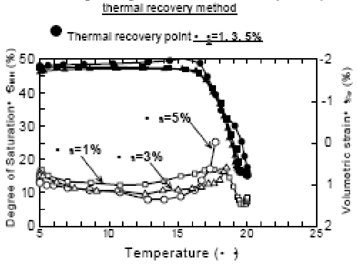
Volume change during dissociation of MH at given isotropic stress condition



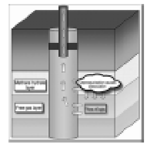
Shear deformation during dissociation of methane hyrtate by thermal recovery method applied given strain level



Volume change during dissociation of methane hydrate by thermal recovery method

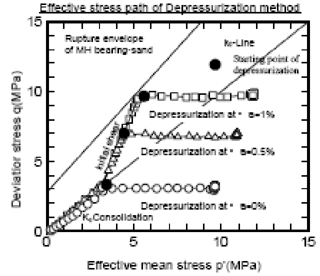


8.2 Depressurization Method

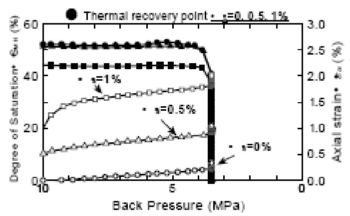


- The depressurization method lowering the pressure inside the well and encouraging the methane hydrate to dissociate. (Methane hydrate dissociates into methane gas and water when depressurized.)

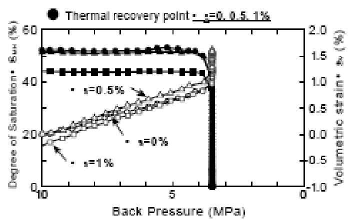
Effective stress path of Depressurization method



Axial strain• MH saturation and B.P. during dissociation of methane hydrate by depressurization method



Volume strain, MH saturation and B.P. during dissociation of methane hydrate by depressurization method



9. Summary of Experiment

- Shear strength increased due to formation of methane hydrate in the sand specimen.
- Shear strength increased with decrease in temperature and increase in backpressure.
- Shear deformation and volume change were quantified during dissociation of methane hydrate.
- Volume change of methane hydrate bearing-sand during depressurization depend on effective stress

10. Constitutive Equation for MH supported sand

1) Modified Cam-clay model was used
2) The plastic strain increment is defined by associative flow rule
3) To express the time dependent elastoplastic deformation within the yield surface, the subloading surface model (Hashiguchi and Oyakasu, 2000) is introduced;
4) The bonding action is introduced as the average effective principal stress component, P_{int}

$P_{int}>0$ indicates the constitutive model for MH-bearing sand
$P_{int}=0$ represents pure sand only

5) To express the plastic deformation behavior in yield surface, the subloading model is applied

11. Outline of the model

□Normal yield surface (sand)

$$p'\left[1+\left\{\frac{q}{M\cdot p'}\right\}^2\right]=p_0'$$

□Subloading surface

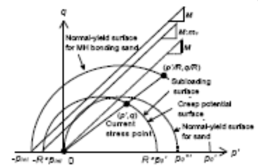
$$(p'+p_{int})\left[1+\left\{\frac{q}{M(p'+p_{int})}\right\}^2\right]=R(p_0'+p_{int})$$

□Normal yield surface (MH-bearing sand)

$$(p'+p_{int})\left[1+\left\{\frac{q}{M(p'+p_{int})}\right\}^2\right]=p_0'+p_{int}$$

□Creep potential surface

$$(p'+p_{int})\left[1+\left\{\frac{q}{m_c(p'+p_{int})}\right\}^2\right]=p_{c0}'+p_{int}$$



◆Evolution law of R

$$dR=U_r\left|d\varepsilon_{ij}^p\right|$$

$$U_r=-u\ln R+\upsilon\left|d\varepsilon_{ij}\right|$$

◆Hardening law of p_0

$$dp_0=\frac{\partial p_0}{\partial p_0^*}\frac{1+e_0}{\lambda-\kappa}p_0^*\Lambda\frac{\partial f}{\partial p}+\frac{\partial p_0}{\partial p_{int}}dp_{int}$$

◆Evolution law of p_{int} defining damage from initial stress p_{int}

$$dp_{int}=\frac{\partial p_{int}}{\partial S_{pe}}dS_{pe}+e^{-\beta S_{pe}}(\underbrace{\frac{\partial L}{\partial T}dT}_{\text{Temperature}}+\underbrace{\frac{\partial L}{\partial P}dP}_{\text{Water pressure}})$$

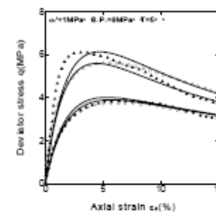
◆Liner coefficient L_c relates to the creep potential surface

$$\Lambda_c=D_{c0}^{*}\exp\left(-\frac{\varepsilon_v^c+\varepsilon_v^p}{\alpha}\right)\frac{1}{\sqrt{\left(\frac{\partial f_c}{\partial p}\right)^2+\left(\frac{\partial f_c}{\partial q}\right)^2}}$$

$$S_{pe}=\Lambda\sqrt{\left(\frac{\partial f}{\partial p'}\right)^2+M^2\left(\frac{\partial f}{\partial q}\right)^2}+\Lambda_c\sqrt{\left(\frac{\partial f_c}{\partial p'}\right)^2+m_c^2\left(\frac{\partial f_c}{\partial q}\right)^2}$$

12. Analytical parameters used in MH model

simbols	[illegible]
λ	slope of the normally consolidated line in e-lnp' space
κ	slope of the overconsolidated line in e-lnp' space
p_i	initial mean effective stress
e_i	[illegible]
M	[illegible]
[illegible]	[illegible]
u	[illegible]
β	[illegible]
γ	[illegible]
χ	[illegible]
ζ	[illegible]
α	[illegible]
D_{c0}^*	[illegible]
ν	[illegible]

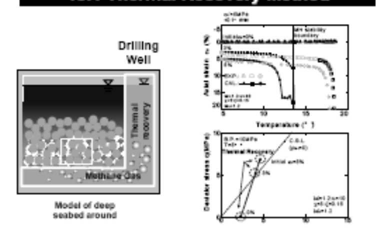


simbols	[illegible]	
	[illegible]	sand
λ	0.148	
κ	0.0018	
p_i	1.2 (MPa)	
e_i	0.973	
M	0.9	
[illegible]	0.9	
u	40	
β	10	[illegible]
γ	10	[illegible]
χ	20	[illegible]
ζ	0.1	[illegible]
α	4×10^{-4}	
D_{c0}^*	-2×10^{-7} min^{-1}	
ν	[illegible]	[illegible]

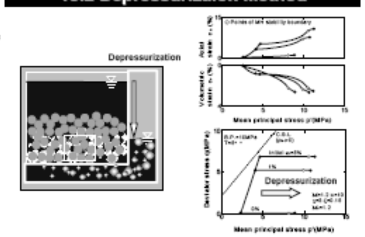
	MH bonding sand	sand	*Strain rate
CAL.	——	——	0.1 %/min
	——	——	0.01%/min
EXP.	▲	●	0.1 %/min
	△	○	0.01%/min

13. Analysis of deformation during MH dissociation

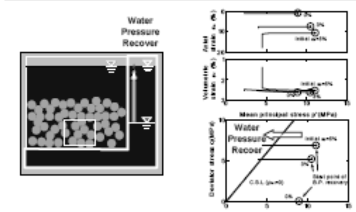
13.1 Thermal Recovery Method



13.2 Depressurizaion Method



13.3 During Water Pressure Recover



14. Summary of Analysis

A time-dependent elastoplastic constitutive model had been proposed for MH-bearing soil in order to clarify the deformation and strength characteristics of the ground associated with the production of MH.Analysis showed that the MH model can reproduce satisfactorily the stress-strain behavior as well as the deformation characteristics of soil with internal bonding forces.It is suggested that if the 14 parameters used in the MH model can be determined appropriately, the changes in temperature and water pressure in time dependent during MH production can be simulated adequately by the proposed model.

Gas Hydrates on the Norway-Barents Sea-Svalbard margin (GANS)

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BACKGROUND

Gas hydrates or clathrates are ice-like compounds of low-molecular-weight gases enclosed within a hydrogen-bonded framework of water molecules. Each volume of hydrate may contain as much as 150-180 volumes of gas. Gas hydrates, most often methane hydrates, can occur naturally in the Earth's shallow sub-surface, e.g. within pores of sedimentary rocks. As their stability is dictated by specific conditions of pressure (high) and temperature (low), gas composition and volume, and pore-water stability, hydrate accumulations in nature are restricted to certain areas: i.e. oceanic sediments on active and passive continental margins, polar permafrost sediments of both continents and continental shelves.

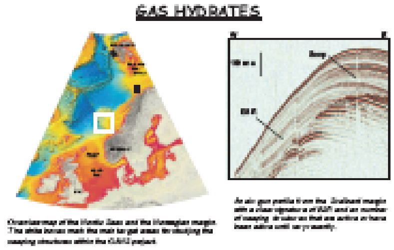
The presence of natural gas hydrates has been confirmed at numerous locations around the world. Their global distribution, combined with their tremendous gas-storing capacity, suggest that: 1) natural gas hydrates form an enormous reservoir of methane carbon and make up an important component of the global organic carbon cycle, 2) they have the potential to become an important future energy resource, and 3) they are very important in determining the stability of submarine slopes.

It is not well understood which additional factors influence the formation and occurrence of hydrates in the sediments and control the fluxes of the involved methane, and by which methods the presence and distribution of hydrates and methane gas in continental margin sediments can be accurately determined in a quantitative way.

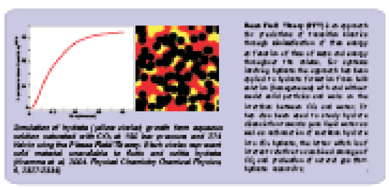
RESEARCH STRATEGIES

In Norway we have research groups with experience on natural seeps and gas hydrates. These features, and processes related to them, are challenging research targets which demand input from different fields if important breakthroughs shall be made. In November 2004 the first national working group on gas hydrates and natural seeps was established (GANS) with participance from academia, industry and governm. institutions. The first national project on gas hydrate, GANS, started 1 October 2006 with a financial support from the NFR-Petromaks programme and the SEABED III industry consortium. The project will last to September 2010.

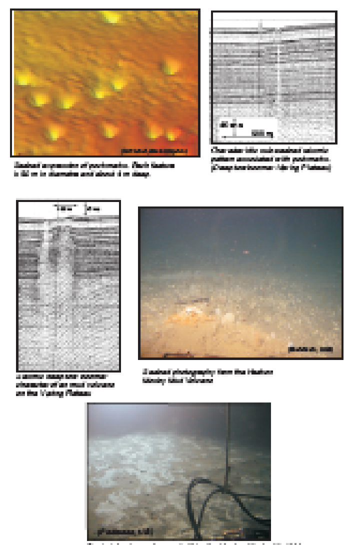
GAS HYDRATES



MODEL TESTS



NATURAL SEEPS/FLUID FLOWS



RESEARCH TASKS

The main research task of the GANS project is to quantify gas accumulations in the 1) form of hydrates in sediments on the Norway - Barents Sea - Svalbard (NBS) margin, including an assessment of their dynamics and impacts on the seabed, and 2) their response on sediments and biota, to provide knowledge vital for a safe exploitation in oil and gas production.

<u>This main task will be obtained through the following sub-goals:</u>

a) Geophysical characterisation of gas hydrates

b) Geological and geochemical setting of gas hydrate reservoirs and seeps

c) Gas hydrate dissociation and its effects on geochemical properties

d) Theoretical and experimental evaluation of gas hydrate dynamics

The GANS Working GROUP[2]

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Stefan Bünz (UiTø)
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ICG

NGI

Wellbore Stability Problems for Methane Hydrate Extraction

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This research is funded by The Norwegian Geotechnical Institute (NGI), International Centre for Geohazards (ICG), Advanced Industrial Science and Technology (AIST) and Cambridge Commonwealth Trust (CCT)

① Background

Numerous researches have been directed on factors that influence the amount of methane gas production in methane hydrate fields. However, a successful methane gas production operation remains questionable as safety concern related to well stability is not fully understood yet. Further research from geomechanics point of view is required in order to have a safe yet economical means of methane gas production. Methane hydrate dissociation induced ***cement sheath breakage in multilayered condition*** has been identified as a forefront topic. The consequence of this phenomenon can be disastrous as it allows methane gas migration to undesired direction in the soil formation. This will not only affect the amount of methane gas production but may also jeopardise the entire operation. In particular, the methane hydrate fields such as Nankai Trough (NT) and Mallik Mackenzie Delta (MMD) encountered a soil profile of alternating layers of sands and clays. Studies using FLAC, a finite difference programme has been conducted in which a modified Mohr Coulomb model (Klar & Soga, 2005) is used.

Fig. 1: Adopted from NRC-SIMS (Steacie Institute for Molecular Sciences)

② Model Formulation

3.1 Coupled deformation

Both soil grains and hydrate are assumed to be incompressible, but the soil skeleton is compressible. The behaviour of compressible water and gas is represented by equations for compressible fluids:

$$\frac{\partial P_w}{\partial t}=\frac{K_w}{S_w n}\left[\frac{1}{\rho_w}\frac{\partial m_w}{\partial t}-n\frac{\partial S_w}{\partial t}-S_w\frac{\partial \varepsilon_v}{\partial t}\right]$$

$$\frac{\partial P_g}{\partial t}=\frac{K_g}{S_g n}\left[\frac{1}{\rho_g}\frac{\partial m_g}{\partial t}-n\frac{\partial S_g}{\partial t}-S_g\frac{\partial \varepsilon_v}{\partial t}\right]$$

The mass balance equations for water, gas and hydrate are:

$$\frac{\partial m_g}{\partial t}=-\nabla\cdot(\rho_g q_g)-\frac{\partial m_{gh}}{\partial t}$$

$$\frac{\partial m_w}{\partial t}=-\nabla\cdot(\rho_w q_w)-\frac{\partial m_{wh}}{\partial t}$$

$$\frac{\partial m_h}{\partial t}=\frac{\partial m_{wh}}{\partial t}+\frac{\partial m_{gh}}{\partial t}$$

The dissociation process follows Kim et al. (1987):

$$\frac{\partial m_{gh}}{\partial t}=-K_d M_g A_{hs} n S_h (P_{eq}-P_g) H[P_{eq}-P_g]$$

$$\frac{\partial m_{wh}}{\partial t}=\frac{M_w N_h}{M_g}\frac{\partial m_{gh}}{\partial t}\text{.......},\quad \frac{\partial m_h}{\partial t}=\frac{M_h}{M_g}\frac{\partial m_{gh}}{\partial t}$$

The specific flows are defined by Darcy's law:

$$q_w=-k_h k_r^w(\nabla P_w-\rho_w g)$$

$$q_g=-k_h\frac{\mu_w}{\mu_g}k_r^g(\nabla P_g-\rho_g g)$$

Value of relative permeability and capillary pressure corresponds to Van Genuchten (1980):

$$k_r^w=S_e^b\left[1-(1-S_e^{1/a})^a\right]^2$$

$$k_r^g=(1-S_e)^c(1-S_e^{1/a})^{2a}$$

$$P_g-P_w=P_c(S_e)=P_0(S_e^{-1/a}-1)^{1-a} \quad \text{where}$$

$$S_e=\frac{S_w}{S_w+S_g}=\frac{S_w}{1-S_h}$$

3.2 Effective stress-strain relationship

The stress-strain relation of soil skeleton is a function of Terzaghi's effective stress defined as:

$$\sigma_{ij}'=\sigma_{ij}-\bar{P}\delta_{ij}$$

$$\bar{P}=\frac{S_w P_w+S_g P_g}{1-S_h}$$

The strength of the soil-hydrate material depends on S_{MH} and the hydrate contribution to the strength is of cohesive nature rather than friction. Modified Mohr Coulomb failure criterion is adopted:

$$f(\sigma_1',\sigma_3',S_h)=\sigma_1'-\sigma_3'N_\phi+2c'[S_h]\sqrt{N_\phi}$$

③ Methane hydrate extraction in layered soils

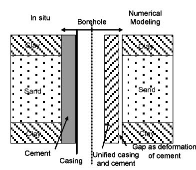

Fig. 2: Condition near wellbore in situ and modelling situation

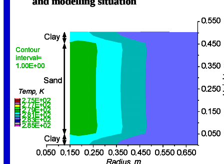

Fig. 3: Temperature profile with thermal consideration

✓ A unified casing and cement as shown in **Fig. 2** has been adopted in NT site to simulate the depressurisation process with the consideration of multilayered condition and thermal aspect (Ng et al. , 2008)

✓ **Fig. 3** shows heat flows from the clay layer to the sand layer leads to faster rate of hydrate dissociation in the hydrate region near the clay-sand boundary than at the centre of hydrate sand layer which will influence the stress distribution.

✓ Arching in the vertical direction was observed due to the difference in the stiffness of clay and sand layer as well as the localised accelerated dissociation at the clay-sand interface.

✓ **Fig. 4** demonstrates that the heat flow from the interface has a greater effect in the case of a smaller thickness at a small thickness of the clay-sand layer.

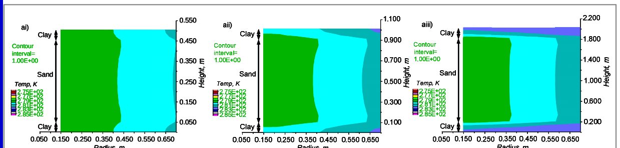

Fig. 4: Effect of soil thickness in which the total thickness of ai) 0.5 m, aii) 1.0 m and aiii) 2.0m

④ Cement breakage risk due to methane hydrate dissociation

Approach: The in-situ wellbore condition which separates the steel, cement and soil is modelled. **Fig. 5** shows the stages when the drilling mud is replaced with cement during the methane gas production. 1D well stability analyses during depressurisation in a supported well are investigated using FLAC. A modified Mohr Coulomb model which is explained above is employed in which effects of S_{MH} on E_{50}, c and ψ are incorporated. The depressurisation sequence is shown in **Fig. 6**.

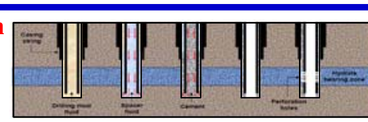

Fig. 5: Stages of cementing in hydrate bearing soil

Initial Conditions: Condition at MMD site, on the coast of the Beaufort Sea, in Canada's Northwest Territories is simulated at around 900m depth (**Fig. 7**) with:

Total vertical stress = 21500 kPa	S_{MH} = 70%	k_o = 0.7
Pore pressure = 11800 kPa	Temperature = 285 K (Isothermal condition)	

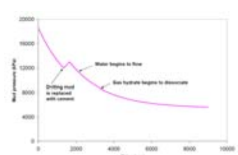

Fig. 6: Depressurisation sequence

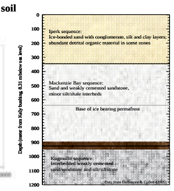

Fig. 7: Soil profile at MMD

Preliminary Results:

✓**Fig. 8a** shows the soil region is in the safe side during the depressurisation process.

✓ The soil is almost in failure state when the mud pressure reaches 12000 kPa in which the replacement is taking place. Therefore, the time for the mud replacement with cement is critical to ensure a safe gas production.

✓ The shear strength of the cement is around 3500 kPa. As shown in **Fig. 8b**, the factor of safety for the cement region would be around 10 at the end of depressurisation.

✓ If soil properties possesses 35% S_{MH}, the soil is failed before the mud is replaced with cement (not shown here).

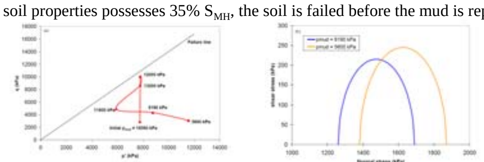

Fig. 8: (a) Soil stress path and (b) cement stress path during depressurisation process

⑤ Future work

The study in MMD sites will be revisited with more parametric studies which include:

✓ Temperature
✓ Pressure reduction rates
✓ Cement properties
✓ Soil properties
✓ Hydrate reformation
✓ Shrinkage of cement
✓2D analyses

All the references stated here can be found in OTC 19364 (2008)

Clathrate hydrate crystals observed via Transmission electron microscope

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Recently the high-magnification observations on clathrate hydrates have been developed to find the evidences of the self-preservation processes of hydrate crystals observed at temperature below 273 K, or to observe the heterogeneous distributions of clathrate hydrates regarding to compositions and/or structures (*e.g.*, Stern *et al.*, 2004; Kuhs *et al.*, 2004). Transmission electron microscope (TEM) is one of the powerful tools to obtain such high-magnification images with obtaining the local diffraction patterns simultaneously. However, due to its high-vacuum condition, there is no report of the TEM observations on clathrate hydrates. The objective of this study was the direct observations of clathrate hydrates via TEM.

We used the tetrahydrofran (THF) hydrate as the sample for the TEM observations. The stoiciometric THF solution was cooled in the refrigerator (at temperatures just above 273 K) to form THF hydrate crystals. This crystal was crashed at liquid nitrogen atmosphere to prepare the thin specimen for TEM (JEOL, type JEM-2010F) observations. To prevent the dissociation of THF hydrates in the TEM observation conditions, at pressures of 10^{-5} Pa, the temperature of specimen was kept at approximately 80 K. To evaluate the analytical process of clathrate hydrates, ice crystals were also observed. The diffraction pattern was fitted with a simulated one to estimate the crystal axis and the lattice parameters.

Figure 1 shows the real image of the ice crystal and the diffraction pattern of the crystal (shown in the inert). We confirmed that the object was the hexagonal ice single-crystal [0001] direction with the lattice parameter of a = 4.65 A. Then we observed the THF hydrates. As shown in Figure 2, the crystal is the structure II clathrate hydrate (cubic, space group: Fd3m, [114] direction) with the lattice parameter of a = 16.8 A. This is the first report of the clathrate hydrate observation via TEM.

Acknowledgment:

A part of this work was supported financially by the Iketani Advancement of Sicence and Technology Foundation (0203003-C). The authors gratefully acknowledge Drs. T. Shibayama and N. Sakaguchi (Hokkaido Univ.) for their support in the TEM observations.

References:

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W. F. Kuhs *et al.*, Phys. Chem. Chem. Phys., 2004, **6**, 4917-4920.

Figure 1: TEM image and diffraction pattern of ice

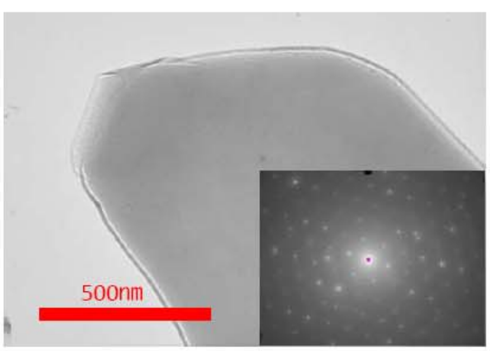
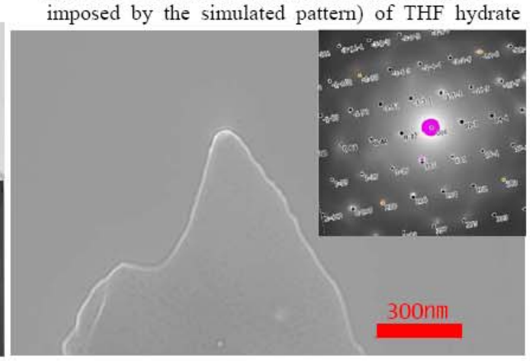


Figure 2: TEM image and diffraction pattern (super-imposed by the simulated pattern) of THF hydrate



Appendix 1 – Workshop Attendees

Last Name	First Name
Abdul	Halim
Allison	Edith
Andersen	Espen S.
Baker	Richard
Bialas	Joerg
Borgund	Anna Elisabet
Brueckmann	Warner
Brugada	Juan
Brunstad	Harald
Chand	Shyam
Chen	Yifeng
Coffin	Richard
Diaz-Naveas	Juan
Digby	Adrian
Drenth	Rik
Fotland	Per
Fujii	Tetsuya
Graue	Arne
Greinert	Jens
Haflidason	Haflidi
Hamdan	Leila
Hart	Patrick
Hjelstuen	Berit Oline
Howard	James
Hyodo	Masayuki
Høiland	Sylvi
Jackson	Peter
Jin	Young Keun
Kit Kong	Liew
Kivela	Pilvi-Helena
Kuznetsova	Tatiana
Kvamme	Bjørn
Langhorne	Nick
Lee	Sook Ling
Lemon	Alexandra
Liu	Shunping
Lorenson	Thomas
Masutani	Stephen
Md Zain	Zahidah
Nihous	Gerard
Nybakken	Stein
Omar	Abdul Aziz
Pecher	Ingo
Rajan	Anupama
Rosenbaum	Eilis
Salehabadi	Manoochehr
Sapranova	Alla
Stoddart	Daniel
Takaoki	Tatsuya

Treude	Tina
Uchida	Tsutomu
Vaular	Espen
Wood	Warren
Yamamoto	Koji